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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Single Pass One-Sided Submerged Arc Welding

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Halter Marine Group, Inc.

Report Documentation Page

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DISCLAIMER

National Shipbuilding Research Project # 7-95-3
SINGLE PASS ONE-SIDED SUBMERGED ARC WELDING

TASK G
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EXECUTIVE SUMMARY

This report is the final report for the NSRP project # 7-95-3, “Single Pass, One Sided Submerged Arc Welding Process”. It summarizes the results of the development, qualification, and production implementation of a new welding procedure and welding backing system for shipboard erection weld joints in the flat position. The objective of the project was achieved and the work was completed in accordance with the tasks outlined in the scope of the work. This report completes Task G, the final task of the project.

NSRP PROJECT # 7-95-3 OBJECTIVE

The objective of this project is to develop and demonstrate an experimental submerged arc welding (SAW) technique(s) and procedure(s) which provides the following:

1) one-side welding capability for erection butt and seam joints,
2) single-pass welding capability in a thickness range from 5/16 to 1 inch (7.9 – 25.4 mm),
3) suitability for an erection stage of ship construction in terms of
    a) portability of equipment,
    b) adaptability to configurations of ship structures, and
    c) tolerance of joint imperfection and tack welds,
4) higher productivity and cost reduction in comparison with existing methods,
5) meeting the ABS qualification requirements for ABS grade steels of both ordinary and higher strengths.

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Task F - Production and demonstration welding.

Task G - Final Report.

2.0 LITERATURE REVIEW OF ONE-SIDED SINGLE PASS SAW METHODS

2.1 BACKGROUND

2.1.1 One-Side Welding

Joining of plates into panels has always been a more productive operation than erection joint assembly because favorable shop conditions allow more advanced welding methods to be utilized. One-sided welding is a method in which the joint is accessed from one side only and welds of acceptable geometry, integrity, and properties are produced on both sides of the joint. The formation of a one-sided weld is possible with the application of a "backing system" under the joint. A backing system is a specially engineered device designed for supporting and shaping the molten root reinforcement. One-sided welding improves efficiency by eliminating the necessity for turning panels over to weld the second side.

Welding of ship sections at an erection site is an extremely difficult and labor-consuming operation. In contrast to the successful proven methods of one-sided welding in the shop environment, erection conditions do not lend themselves to one-sided single pass welding techniques. The construction tolerances and plate distortion from earlier burning and welding operations produce inconsistent fit-up and alignment problems. One-side multi-pass welding methods (FCAW/SAW) are suitable for erection joints, however multi-pass welding is less productive and is associated with a higher level of distortion.

2.1.2 Characterization of Erection Deck Joints.

Specific features must be taken into account when developing the design requirements for a one-sided backing system.

1) Distortion that develops from previous burning and welding operations causes plate warpage and creates edge alignment problems. This calls for the backing systems to be as insensitive to plate misalignment as permitted by specifications.
2) Construction tolerances are greater than shop conditions. Backing systems must have wider tolerances for root openings.
3) Due to limited and difficult access to the back side of the joint, backing systems must be brought to the joint and installed manually. The systems are required to be portable, lightweight and easy to handle.
4) Space available under the joint is often limited by access holes cut in the transverse frames running across the joint. This puts restrictions on the allowable cross-sectional dimensions of the backing system.

2.2 STATIONARY BACKING METHODS FOR ONE-SIDED WELDING

The most important stationary one-sided welding techniques are discussed with emphasis on Copper-Backing (CB), Flux-backing (FB), Flux-Copper Backing (FCB), Refractory-Flux Backing (RF) methods, and also some of their variations. These methods are compatible with the SAW process and a single-pass technique, the features which are relevant to the objectives of the current project. The importance of discussing stationary one-sided welding methods also lies in the fact that many features of the stationary backing systems have been adopted into the design of portable backing systems which are used for erection welded joints.

2.2.1 Copper-Backing (CB) Method

This CB method was developed in the U.S. in the early 40's for one-sided welding but has not found wide spread application in the shipbuilding industry because of serious drawbacks . However, the most important features of this method have laid the foundation for development of the most popular and productive one-sided welding method today, the flux-copper backing (FCB) method.

Fundamentals of Copper-Backing Method. With the copper-bar method a full penetration weld is accomplished from one side of the joint. The main component of the backing system used in any CB method is a copper bar that is pressed against the back side of the joint length.

Drawbacks of CB Method. The copper bar is used as a stationary backing system installed permanently in a predetermined position and the fitted plates are transported to the backing system. Poor contact between the copper bar and the plates caused by plate misalignment or distortion from previous operations creates defects such as undercut or overlap. The adjustment of the copper bar relative to the joint is difficult when the plates are in place. As a result, CB backing systems would be difficult to adapt for field erection joints. Root welds are not consistent and there is a cracking tendency due to copper inclusions.

2.2.2 Flux-Backing (FB) Method

The flux-backing (FB) method was one of the first one-sided welding methods developed in the U.S. in the late 30's. Often called the "flux-cushion" method, it has been traditionally associated with SAW. Despite some advantages over the CB method, there has not been a wide spread application of the flux-cushion method except for thin plates.

FB Technique. The backing system consists of a steel trough and an inflatable fire hose laid on the bottom of the trough. A refractory cover is tightly attached to the sides of the trough to protect the hose from possible contact with molten metal. Backing flux fills the rest of the trough. The trough is clamped to the backside of the plates along the entire length of the joint to be welded. When the fire hose is inflated by compressed air, the flux is pressed against the back side of the joint creating a so called "flux cushion".

Advantages and Drawbacks of the FB Method. The FB backing system is more adaptable to plate edge misalignment since the backing flux is in firm contact with the plates, leaving no gaps under the joint that might attribute to defects such as melt-through, undercut, underfill, and slag inclusions. These defects are frequently encountered with the CB method, a result of poor plate to copper bar contact. Portability of the FB system is limited because it is predominantly used as a stationary system. The system consists of a bulky steel frame, powerful electromagnetic devices and a long steel trough. The magnitude of welding current is limited because the flux backing does not provide a solid foundation for the molten metal and as a result irregular root reinforcement is developed along the joint.

2.2.3 Flux-Copper Backing (FCB) Method

The Flux-Copper backing method was first introduced in the USSR in 1949. Kobe Steel developed its own improved version of the FCB method used for practical applications in Japan since 1964 (Task A). Today the FCB method remains one of the most productive of all one-sided welding methods in ship construction.

FCB Technique. This method provides backing with a copper bar and a flux-cushion simultaneously (Fig. 2-1). A thin layer of special backing flux is spread uniformly on top of a flat copper bar and an inflatable pneumatic hose is laid on a support frame (not shown) installed under the plates to be welded. A refractory cover (not shown) is used to protect the hose from possible damage by heat transferred through the copper bar.

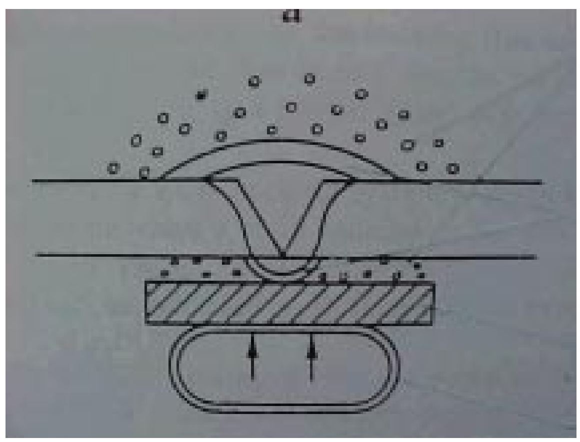


FIGURE 2-1 FLUX-COPPER BACKING METHOD

With this technique, the backing flux is in contact with the plates rather than a copper bar. The copper-flux backing system acts as a flux-backing system known for its reliable contact with the plates leaving no gaps under the plates that might cause overflow, undercut, underfill and slag inclusions in the root bead.

Advantages and Drawbacks. Both the Copper-Backing (CB) and the Flux-Backing (FB) methods have serious drawbacks and are not reliable in providing acceptable quality. The Flux-Copper (FCB) backing combines the advantages of both methods while eliminating their drawbacks (Task A). The FCB system acts as a Copper-Backing system known for its capability to maintain uniform root reinforcement and allows higher current to be used. Portability of the FCB is limited because it is a complex stationary system. The system consists of a bulky steel frame, powerful electromagnetic devices and special mechanisms needed to adjust the position of the copper bar relative to the joint.

2.2.4 Refractory Flux-Backing (RF) Method

The stationary RF (Refractory flux) welding method was developed in Japan by Kobe Steel in the late 60's.

RF Technique. This technique similar to the flux-cushion method consists of a steel trough, a refractory cloth tightly attached to its sides, an inflatable fire hose laid under the cloth and special RF-1 backing flux which fills the trough above the cloth. When the hose is inflated by compressed air, it presses the flux against the back side of the joint creating a flux cushion. The RF-1 Flux contains a small amount of thermosetting phenolic resin. During welding as the temperature of the RF-1 flux ahead of the arc reaches 150°-250 °C (302°-392 °F), the phenolic resin hardens momentarily and turns a layer of granular flux into a solid crust.

Advantages and Drawbacks of RF Method. The RF method has been successfully utilized in Japan under stationary shop conditions that provide sufficient space for a large and bulky backing systems. Welding equipment and accessories are associated with precisely prepared joints with tight tolerances.

2.3 ERECTION BACKING METHODS FOR ONE-SIDED WELDING

2.3.1 Kataflux (KL) Method

The Kataflux backing system consists of short consumable backing units assembled under and along the entire joint (Task A). Each unit consists of a short trough made from thin steel and filled with two layers of backing materials. The top layer is granular flux and the bottom layer is solid refractory flux. The refractory material supports the molten metal much like a copper bar. The KL-1 units are installed using strongbacks and wedges or special jigs.

2.3.2 Flux-Asbestos Backing (FAB) Method

The FAB-1 unit is typically 2 feet long and composed of the following components. A corrugated cardboard pad at the bottom of the unit maintains uniform contact pressure on the upper layers. The layer on top of the cardboard is made of refractory material (originally asbestos) that provides fire protection for the cardboard. The next layer is made of solid refractory flux to provide support for the molten metal and a uniform height of the root bead. The top of the unit is made of several layers of fiberglass tape to provide good appearance of the root bead. The entire unit is wrapped in thin film to hold the components together and protect backing from moisture. Permanent magnets are used to help facilitate clamping of the backing to the underside of the joint.

2.3.3 Portable FCB Method for Erection Joints

The portable FCB one-sided welding method was developed for erection joints from the original stationary FCB method by utilizing short portable copper backing bar segments. The segments are rather heavy despite being short (1" x 4" x 2' bar, 31lbs.). A reinforcement groove is made in the middle of each segment. The backing flux is placed in the reinforcement groove in advance.

2.3.4 Portable RF Method for Erection Joints

Only one modification of the RF method is known to be used at erection sites. The backing system consists of a chain of copper bar segments. The reinforcement groove in each segment is filled with granular RF-1 flux containing thermosetting resin as described earlier. The copper bar and the flux are baked in a furnace or by a gas flame torch prior to welding, hardening the granular flux into a solid flux backing. This method can be used with SAW, GMAW, and FCAW.

2.3.5 Ceramic Backing for Erection Joints

Ceramic tape is one of the most common weld backing methods used in the shipbuilding industry. Its application is prevalent for deck butt root pass welds (FCAW) followed with the SAW process for fill and cover passes. The FCAW process is adaptable to erection joint tolerances but multi-pass welds are less productive.

2.3.6 Summary of Literature Review

The main goal of this literature review was to research and identify one-sided single pass submerged arc welding (SAW) methods most suitable for welding steel butt joints at the erection stage of construction. The most popular portable erection backing methods for one-sided welding are the KATAFLUX and FAB backing methods. The drawbacks of these backing systems are the high cost of the consumable backing and the low tolerance to joint conditions. The most successful one-sided welding systems are the stationary FCB and RF methods. These methods have the most potential for modification and development. As a result of this review the best approach is to develop a new welding method using acquired information.

3.0 DESCRIPTION OF THE EXPERIMENTAL (MRF) ONE-SIDED WELDING METHOD

3.1 BACKING SYSTEM

3.1.1 Principles of the Modified Refractory Flux (MRF) Backing System

The MRF one-side welding method is based on the original one-sided refractory flux (RF) welding method and the flux-copper backing (FCB) method. The weld pool is formed on a solid support created by a special backing flux that contains a small amount of thermosetting resin. Initially in a granular form, the backing flux hardens in front of the moving arc when heat is transferred by the welding arc and the flux temperature reaches 150° - 200° C (302° - 392° F).

The backing flux turns into a solid briquette (flux cake) developing a maximum compressive strength that supports a weld pool of a certain volume and weight. If the flux is heated to lower temperatures, the strength of the flux cake is not sufficient and the molten metal falls through the weld joint creating so-called "melt-through" conditions.

A thin surface layer of the flux cake is melted by the weld, protecting the weld from the surrounding atmosphere giving a silvery and shiny appearance to the root reinforcement surface.

<u>Design of Prototype Backing System</u>. The prototype backing system was designed and fabricated based on these requirements.

1) The backing system should not be consumable, but reusable and have a long service life. This may render the one-time procurement cost of such a system to be quite high. This cost may be amortized over significant footage of welds performed before the system (or portions) needs replacement. Only the cost of a backing flux consumable will add to the direct cost of welding.
2) The trough's cross-section shall not exceed a maximum 1 _" radius to permit trough passage through deck stiffeners transverse to the joint.
3) The trough shall be designed to contain a flux cushion.
4) The backing system should consist of short identical units for easy handling. The trough of the backing system should be made of light-weight but strong metal that conducts and dissipates heat transferred from the welding area.

3.1.2 Description and Fabrication of Prototype Backing System

The backing system used for the experimental program consists of two backup units installed under the 4 ft. test joint. Each backup unit is 2 ft. in length to better accommodate the conditions typical for erection joints. Each backup unit consists of the backup assembly and two magnetic clamp assemblies.

<u>Backup assembly</u>. The backup assembly consists of the aluminum trough, copper backup bar and ceramic cloth bar cover. *The trough* is a rigid base made of high strength 2-3/4 in. diameter 6061 aluminum pipe cut lengthwise (Fig 3-1). The length of the trough is 24 inches and weighs 2 lbs. 6oz.. The aluminum trough is modified to increase the tolerance of the backing system at high heat input. The longitudinal edges of the aluminum trough are machined and a strip of stainless steel is attached to each edge. Now the strips rather than aluminum edges are in contact with the high temperature plates. This modification is required because the edges of the original trough were occasionally damaged by high temperatures transferred from the weld plate.

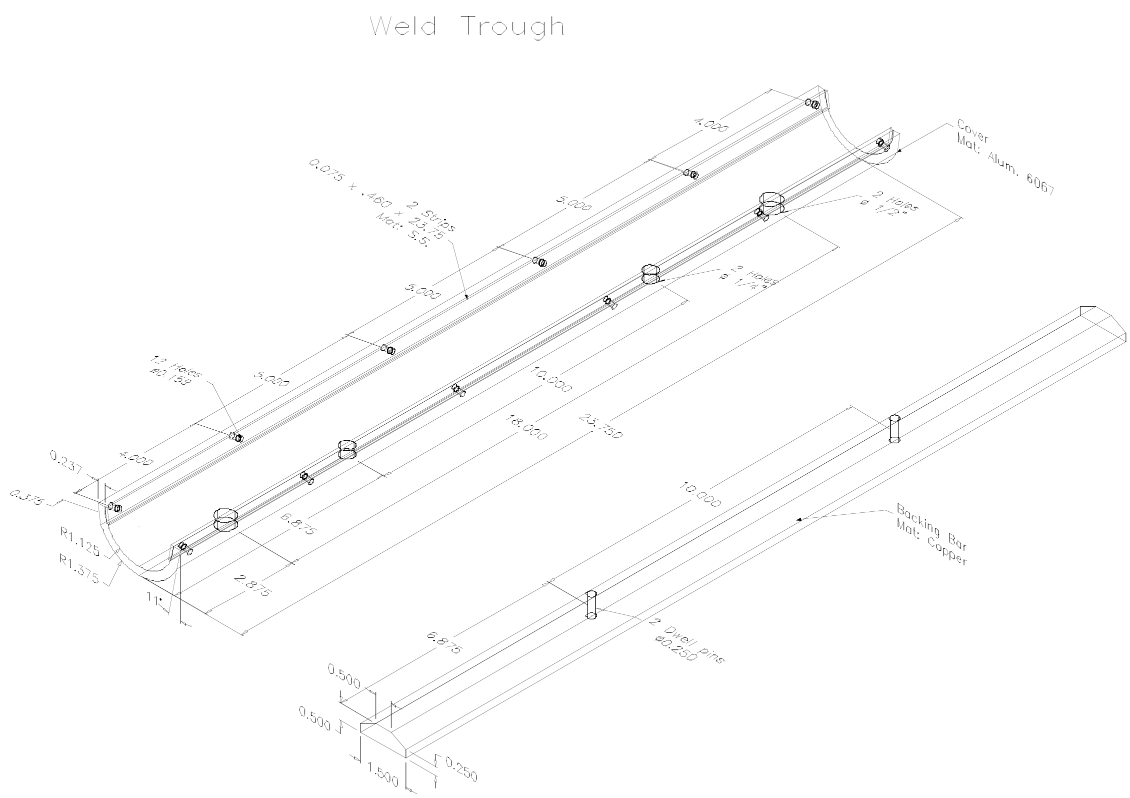


FIGURE 3-1 ALUMINUM TROUGH DESIGN

Initially a 1/2 in. thick aluminum *backup bar* was used in the trough but it has been replaced with a copper backup bar that proves to be more reliable because it can withstand higher temperatures and does not sustain serious damage in a weld melt-thru accident. The weight of the copper backup bar is 4 lbs. 10 oz..

FIGURE 3-2 ALUMINUM TROUGH WITH COPPER BAR / BAR COVER / AND FLUX

The *bar cover,* made of a heat-resistant relatively inexpensive alumina-based ceramic tape by Cotronics (3,000^{o}F maximum service temperature) is laid freely on top of the backup bar (Fig. 3-2) to protect the bar from welding heat and accidental contact with molten metal. Masking tape is applied to each end of the trough before adding the backing flux. The trough is filled with RF-1 flux, level with the edges of the stainless steel strips. The troughs are then positioned under the joint and secured with magnetic clamps (Fig. 3-3).

FIGURE 3-3 MAGNETIC CLAMPS SUPPORT TROUGH

Magnetic Clamp Assembly. Two magnetic clamp assemblies secure the trough to the backside of the plates and press the flux against the joint. The weight of one magnetic clamp assembly is 8 lbs. 2 oz..

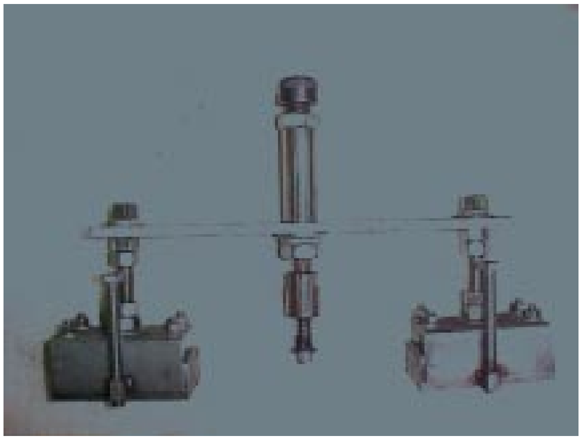


FIGURE 3-4 MAGNETIC CLAMP ASSEMBLY

FIGURE 3-5 CLAMP ASSEMBLY SUPPORTS TROUGH

The magnetic clamp assembly (Fig. 3-4) consists of the following components:

1) Aluminum flat bar
2) Two permanent magnets
3) Pusher subassembly

The Aluminum flat bar (1lb., 5/16" th.) provides the necessary rigidity for support of the trough. *The permanent magnets* (45 lbs., max. pull) are mounted to the aluminum flat bar with stainless steel bolts. *The pusher subassembly* is inserted through the hole in the trough and pressure is transferred by the backup bar to the joint backing flux (Fig. 3-5). The upward force applied to the backup bar is preset by the allen screw adjustment on the pusher subassembly. As the heat of the welding process causes flux shrinkage, the spring on the pusher subassembly ensures constant upward force on the backup bar which maintains compression of the backing flux against the joint surface.

3.1.3 Backing System Application

Installation of the Backing System consists of the following operations:

1) Replace ceramic tape if needed. The tape may burn out from previous welding operation. Fill the trough with backing flux in excess of the quantity required and level the flux flush with the edges of the trough.
2) Install the trough to the backside of the joint so that the joint is in the center of the trough.
3) The backup assembly is temporarily clamped to the plates by auxiliary clamp(s). The auxiliary clamp(s) relieves the installer from holding the backup assembly.

4) Align the trough with the joint and position the first of two magnetic clamp assemblies, inserting the pusher subassemblies allen screw into the corresponding hole of the trough. Repeat this step for the second magnetic clamp assembly.

The trough installation procedure is repeated for the remainder of backup units. When the backup units have been attached for the full joint length, iron powder is then added to the joint groove from the top side and leveled to the required height with a special template.

3.2 WELDING TECHNIQUE, EQUIPMENT AND MATERIALS

3.2.1 SAW Tandem Arc Welding Process

Good single bead formation of the root and face surfaces of a weld joint are extremely difficult using the one-sided single pass single electrode welding technique. Two electrodes operating simultaneously and arranged in tandem are used in this program because the geometry of the root and face welds can be controlled independently. With a single pass tandem electrode arrangement the lead arc forms the root weld. The trailing arc fills the remainder of the groove and provides sufficient face reinforcement. Both electrodes weld in one pool but are separated sufficiently to allow partial solidification of the root weld. This welding technique utilizes a DCEN (straight polarity) lead electrode and an AC trail electrode under special conditions to achieve one-sided single pass welds with the MRF backing system.

3.2.2 Power Supplies

DC Power Source -- A variable voltage direct current (DC) welding power source is selected for the leading arc. The L-TEC VI-1200 DC power source has the following characteristics.

--- L-TEC VI-1200 ---

• Rated output at 100% duty cycle	1,200 A @ 44 VDC
• Output voltage (for 460 V) Low:	20-38 VDC @ 700 A
High:	34-44 VDC @ 1,200 A
• Open circuit voltage:	64 VDC
• Input voltage:	460 VAC, 3 Phase, 60 Hz
• Input current:	106 A @ 460 VAC

AC Power Source -- A variable voltage alternating current (AC) welding power source is selected for the trailing arc. The Lincoln Idealarc AC-1200 power source has the following characteristics:

--- LINCOLN IDEALARC AC-1200 ---

• Rated output at 100% duty cycle	1,200 A @ 44 VDC
• Output current (for 460 V) Low:	200 A - 600 A
Medium:	200 A – 1,500 A
High:	900 A – 1,500 A
• Input voltage	460 VAC, 1 Phase, 60 Hz
• Input current @ rated load:	182 A @ 460 VAC

3.2.3 Welding Tractor

Two control boxes are mounted on the L-TEC UWM-37 heavy-duty carriage. The UEC-8 welding control box is used for the lead arc with the DC power source and welding torch assembly. The Lincoln NA-3 control box is used for the trailing arc with the AC power source. The L-TEC UWM-37 utilizes the J-governor control box. The flux hoppers capacity is 25 lbs. with vacuum recovery.

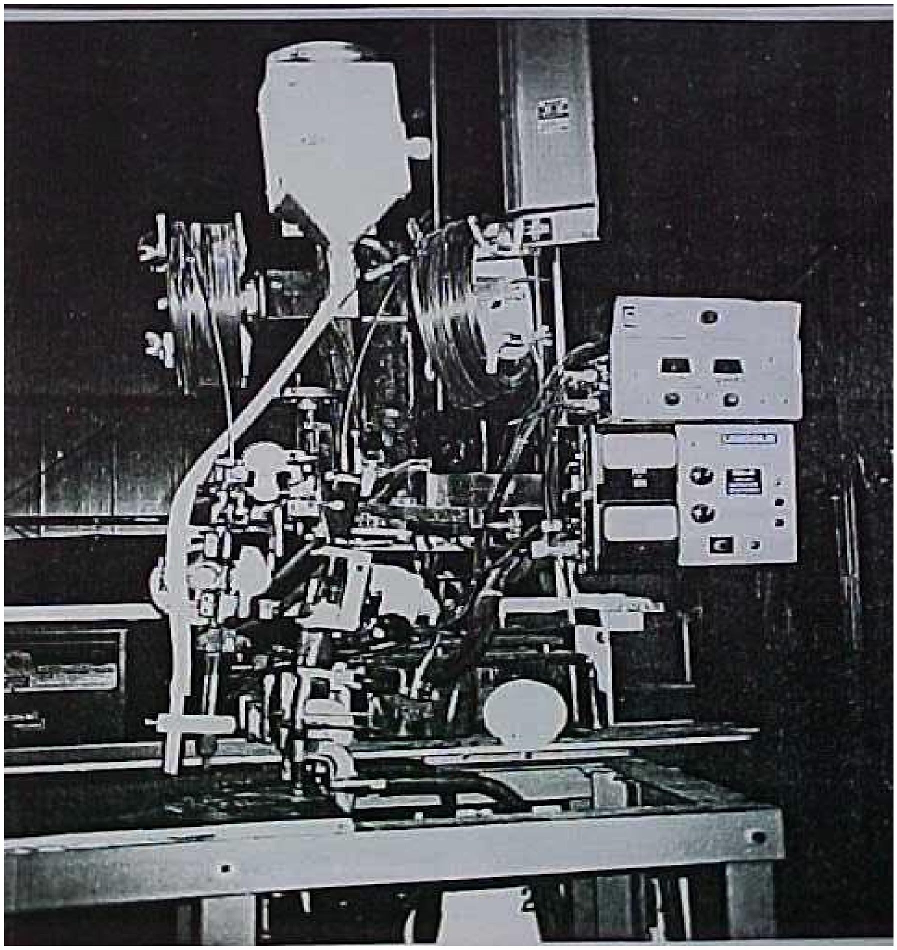


FIGURE 3-7 TANDEM ARC WELDING TRACTOR

3.2.4 Base Metal

The following ABS grades of plate material are selected for experimental weld tests.

a) Gr. A and AH-36 (tests for welding equipment set-up and technique development – 3/8”, 11/16”, 1”)

b) Gr. DH-36 & EH-36 (tests for mechanical properties and procedures – 5/16”, 11/16”, 1”)

The test assembly dimensions are 12”x 48”(length) and the plate edges are prepared with 22.5 degree bevels. The plate’s rolling direction is perpendicular to the joint groove axis.

3.2.5 Welding Consumables

It is not possible to duplicate the planned experimental program for all of the consumables selected as candidates and so the consumables with the most promising characteristics are implemented for testing.

Electrodes -- The solid wire electrodes selected for testing are the Lincoln L-60, L-61 and L-70.

- Lincoln L-60 & L-61, 5/32 in. diameter wires (Specification A5-17, EM12K)
- Lincoln L-70, 5/32 in. and 3/16"diameter wire (Specification A5-23, EA1)

Iron Powder -- Iron powder is added to the groove of the joint to facilitate formation of the root weld. Iron powder increases welding productivity and provides tolerance for root opening variations. It is procured from Pyron Metal Powder Inc..

The Chemical composition of iron powder is given in Table 3-1. The welding grade of iron powder (WG-1) has low carbon (C), sulpher (S) and phosphorus (P).

Table 3-1. Chemical composition of iron powder

Iron Powder		C	Mn	Si	P	S	O	Cu	Cr	Ni	Mo	Al
		(weight percentage)										
WG-1 [1]	(min)	0	0	0	0	0	0.03					
	(max)	0.03	0.50	0.05	0.02	0.05	0.43					
WG-1 [2]	(cert)	0	0.26	0.006	0	0.018	0.13	0.028	0.048	0.010	0.004	0.013

Notes: 1 -- per Pyron Product Specification
2 -- per Pyron Certification of Analysis

Fluxes -- These welding and backing fluxes, selected as candidates for testing are ordered from domestic and foreign suppliers:

a) Welding Fluxes:
- Lincoln 880M (Lincoln Electric)
- Lincoln 761 (Lincoln Electric)
- Kobe PFI-50 (Kobe Steel, Japan)

b) Backing Fluxes:
- Kobe PFI-50R (Kobe Steel, Japan)
- Kobe RF-1 (Kobe Steel, Japan)

After initial testing Kobe PFI-50 flux was selected for welding and Kobe RF-1 was selected as the backing flux.

4.0 DEVELOPMENT OF MRF ONE-SIDED WELDING METHODS

4.1 PROCEDURE / TECHNIQUE DEVELOPMENT -- 11/16" PLATE THICKNESS

4.1.1 Process Parameters (Root Weld)

A detailed study of root bead formation is undertaken to investigate the effects of welding variables on the weld fusion characteristics. Macrostructure examinations of weldments are analyzed to evaluate the following characteristics.

1) Internal weld defects -- Macro specimens are inspected for various types and causes of internal defects (cracks, porosity, incomplete fusion, slag inclusions, etc.).

2) Weld geometry -- Measurements of the weld fusion characteristics are recorded from macro specimens of the weld cross-section.

The root bead's profile is defined by the weld fusion characteristics shown in Figure 4-1. The weld geometry of the root face is critical to adequate interbead fusion. Depositing a large root bead is important to reduce the possibility of trailing arc melt-thru, but the formation of slag pockets from interbead lack of fusion is common when the root crown height is excessive.

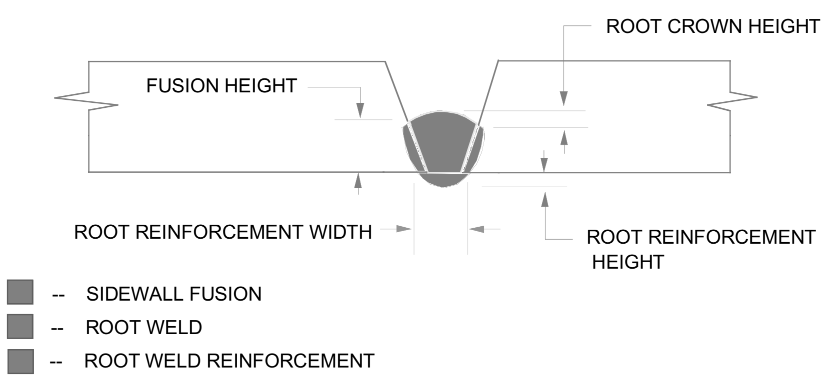


FIGURE 4-1 CROSS SECTION OF A ROOT BEAD

<u>Effect of Current Type</u>. Testing is performed with AC, DCEP and DCEN current to investigate and compare effects on root bead geometry and heat input.

Characterization of DCEP Polarity. Weld penetration with DCEP polarity is excessive, causing root weld melt-thru conditions. To avoid damage to the backing system at higher currents and larger root openings, further experiments are discontinued.

Characterization of AC Polarity. Advantages offered by AC current are the increased fusion height and reduced crown height of the weld geometry. The shape of the root reinforcement is excellent and the weld root face is slightly concave.   However, even with the extremely high heat input, the deposition rate does not match DCEN polarity deposition rates.   Also AC current is not as tolerant to root gap variations.

Characterization of DCEN Polarity. Direct current electrode negative polarity used for the lead arc is a distinguishable feature of the MRF welding method and the reasons for selecting this current choice are summarized here.

1) DCEN polarity provides higher deposition rates which are beneficial for the trailing arc since it eliminates the possible melt-thru conditions attributable to thin root passes. Deposition rates of DCEN and DCEP polarities at 700 Amps, are 0.56 lb./min. and 0.40 lb./min respectively (Task C).
2) DCEN polarity provides low weld penetration, an attractive feature for the root welds on the relatively thin layer of MRF backing flux.   Penetration with DCEN polarity is 20-25% lower than with DCEP polarity (Task C).
3) DCEN polarity is adaptable to root opening variations.

DCEN polarity is sensitive to electrode alignment due to its low penetration characteristics and therefore joint centerline positioning of the electrode is critical to avoid incomplete penetration and slag inclusions.

Effects of Current.   Selection criteria for optimal current must satisfy the objectives of proper bead geometry that include maximum root fusion height, minimal root crown and adequate root reinforcement.   The welding conditions are given in Table 4-1.

TABLE 4-1. WELDING CONDITIONS

Plate Thickness	*Included Angle*	*Iron Powder Fill Height*	*Root Opening / Face*	*Electrode Drag Angle / Extension*
11/16”	**45°**	**7/16” (50%)**	**1/4" / 0”**	**15° / 1 5/8”**

CONSUMABLES : Lincoln L-60, 5/32” dia.; WG-1 Iron Powder; RF-1 Backing Flux; PFI-50 Welding Flux

Effect *of current on fusion height.*   The trend welding current has on the fusion characteristics is evident in the macro photos (Fig. 4-2) of joints welded at specified amperage settings with other variables held constant. Increasing current (between 600A to 800A) has a minor effect on the root fusion height but the root crown height increases significantly from 1/32” to 5/16”.   The root crown is beneficial in the prevention of trailing head melt-thru conditions and for the increased weld metal volume, but when the root crown becomes too large (i.e. - amperages greater than 800A) areas with deep slag pockets become potential sites for interbead lack of fusion.

600A / 24V / 15.6ipm 700A / 24V / 15.6ipm 800A / 24V / 15.6ipm

FIGURE 4-2 WELDING CURRENTS EFFECT ON ROOT WELD FUSION CHARACTERISTICS

When the current of the trailing arc is increased sufficiently to melt the slag pockets, there is a greater risk of root bead remelt and possible blow-thru. Optimal current of the lead arc facilitates adequate root fusion without detrimental slag pockets.

Effect of current on root reinforcement. This process provides acceptable root reinforcement in shape and contour through a relatively wide current range (700A – 900A) when other variables are properly selected. Arc penetration with welding currents of 600A and below sometimes produce inadequate root reinforcement.

<u>Effects of Voltage</u>. The welding conditions are given in Table 4-1 and the trend welding voltage has on the welds fusion characteristics is shown in Figure 4-3.

Effect of voltage on fusion height. Photos of macro specimens show slag pocket formation when the voltage drops below 24V. Root crown height is the fusion characteristic affected most by voltage change. Excessive root crowns are created at voltage settings below 22V (unacceptable slag pockets).

Effect of voltage on root reinforcement. Root reinforcement height does not fluctuate significantly (0” – 1/16”) in the voltage range of 22V to 26V.

700A / 22V / 15.6ipm 700A / 24V / 15.6ipm 700A / 26V / 15.6ipm

FIGURE 4-3 WELDING VOLTAGE EFFECT ON ROOT WELD FUSION CHARACTERISTICS

<u>Effects of Travel Speed</u>. Travel speed is set at a minimum of 15 ipm. When travel speeds fall below 15 ipm the HAZ mechanical properties deteriorate because of high heat input and extremely low cooling rates.

<u>4.1.2 Welding Conditions</u>

<u>Effects of Joint Geometry</u>. Joint geometry is varied to simulate conditions typical in a ship erection environment. Common variables investigated are the root opening, root face variation, plate misalignment and electrode misalignment.

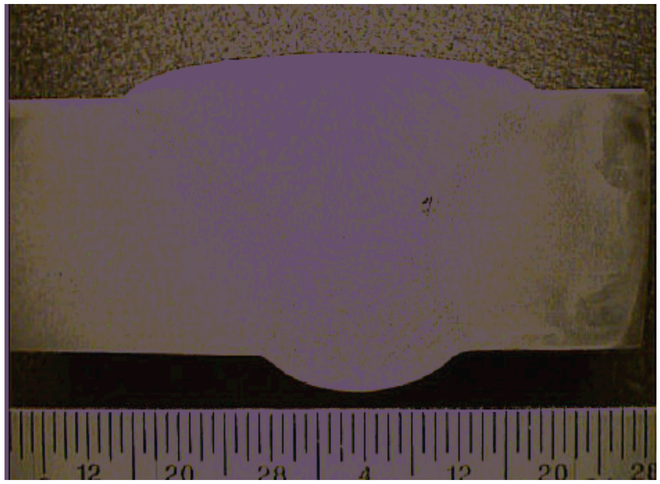
<u>*Root Openings*</u>. Root openings from 0" to 1/4" are tested. Results show to obtain maximum sidewall fusion, and minimum root weld crown height, the optimum amperage range is 700A to 800A. Root reinforcement is adequate with an amperage range of 700A to 900A.

Effect of Root Openings on Iron Powder Volume. Fitting tolerances for root openings (1/16" to 3/8") and included angles (30^{o} to 45^{o}) are not critical to welding when the groove is filled with a predetermined level of iron powder. The percentage of iron powder changes from 45% to 56% by volume (Task C), a difference of 11%. Erection joint design variations of this range are unlikely to occur in the same joint. Testing showed the iron powder level does not need to be adjusted to accommodate for these variations in joint design.

<u>*Root Face Variations*</u>. The effects of a joint root face are unfavorable in most instances. Root faces of 1/16" are marginally beneficial, improving the root reinforcement uniformity, but with joint root faces of 1/8" and 3/16", root reinforcement becomes inadequate and the weld fusion characteristics deteriorate. The weld crown height increases and the fusion height decreases. Root faces of 1/4" do not require testing.

<u>*Plate Edge Misalignment*</u>. Test results from joints with 1/4" root openings demonstrate plate edge misalignment is tolerable up to 5/32" with the MRF one-sided welding method. Two weld test plates are assembled with plate edge misalignments of 3/32" (W98-10) and 5/32" (W146-9) . Both weld test joints have acceptable root reinforcement results (Task C).

<u>Electrode Misalignment</u>. Offset of the leading or trailing electrode relative to the centerline have a detrimental effect on the weld geometry causing interbead lack of fusion (Fig. 4-4). Interbead slag pockets may form on either side of the groove because the face weld is deposited over asymmetric root welds.



Test No. 114
Figure 4-4

Electrode offset seam tolerances are investigated with an experimental (4 ft.) test assembly fit with a 1/4" root opening. The carriage track is aligned with the joint centerline in such a manner that produces the following electrode offsets:

1) At D = 10.0 in. electrode offset is 1/8" (right side of joint centerline)
2) At D = 20.5 in. electrode offset is 0" (electrode is in the center of the joint)
3) At D = 31.0 in. electrode offset is 1/8" (left side of joint centerline)

When the tractor moves along the guiding track, electrode offsets from the joint centerline change gradually toward the right or left side of the joint (relative to the direction of welding). The resulting weld is sectioned in several places, at D = 10 in. and 31 in.. Two weld cross-sections, W142-10 and W142-31 (Task D) represent offsets of +1/8" and –1/8", respectively. Test results from experiment show the following:

1) Weld W142-10 is made with the electrodes offset toward the right side of the joint. The left side of the root bead is fused insufficiently forming a deep slag pocket. The trailing arc failed to completely remelt the slag pocket and leaving a slag inclusion.
2) Weld W142-31 has the same offset but toward the left side of the joint. This weld is properly fused, with no slag inclusions.

Electrode offsets of 1/8" are unacceptable as determined from the inconsistent test results. Electrode offset tolerances are set at 1/16 in.. This tolerance is critical considering misalignment can occur as a result of initial electrode alignment, poor joint tracking and inadequate wire straightening.

Effects of Iron Powder Levels

Experiments are conducted to study effects various iron powder levels have on the root bead geometry. Root welds are made using the welding conditions of Table 4-1 (11/16" plate thickness) and the 30^{o} included V-Groove joint design with lead arc parameters of 700Amps and 24Volts.

The objective of this test is to determine the tolerance of the procedure to variations in amounts of iron powder from 25% to 100%. The joint root opening for all of the tests was 1/4". Templates are fabricated to measure and level the quantities of iron powder in the joints and these fill levels are shown here.

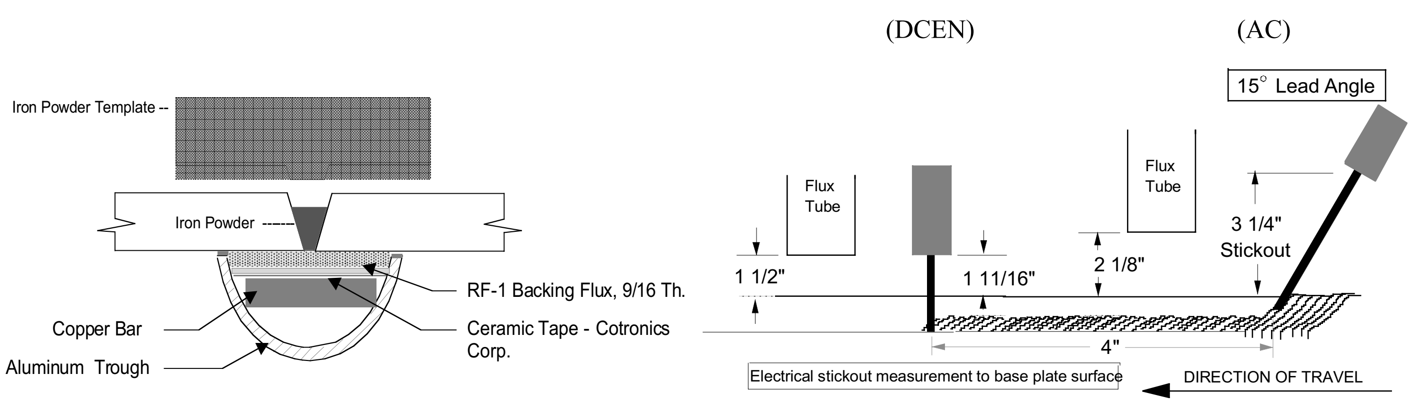
1) Fill level = 0.250 in. (25% of joint groove area) Unacceptable: Weld melt-thru
2) Fill level = 0.437 in. (50% of joint groove area) Acceptable
3) Fill level = 0.562 in. (75% of joint groove area) Unacceptable: Unfused root edges
4) Fill level = 0.687 in. (100% of joint groove area) Unacceptable: No root reinforcement

Acceptable root reinforcement can be obtained even at 100% iron powder levels with various root openings if current is increased to 900A. Unfortunately a very large crown is developed that makes the completed weld vulnerable to incomplete fusion and slag inclusions. The best shape of root reinforcement is achieved at an iron powder fill level equating to 50% of the joint groove area.

4.1.3 Preliminary Tests

The objective of these preliminary tests are to ensure that weld quality satisfies nondestructive and destructive testing requirements in accordance with ABS Rules for Building and Classing Steel Vessels. Nondestructive examination methods include visual and ultrasonic inspection methods with follow-up macro examinations of weld joint cross sections. Destructive tests performed, include transverse tensile tests, all weld metal tensile / yield tests, bend tests and CVN impact tests.

MRF - WELDING TECHNIQUE



Range of root openings proposed for this Joint design are : 1/8" to 5/16".

Welding parameters for procedure designations developed in Task D are given in Table 4-2.

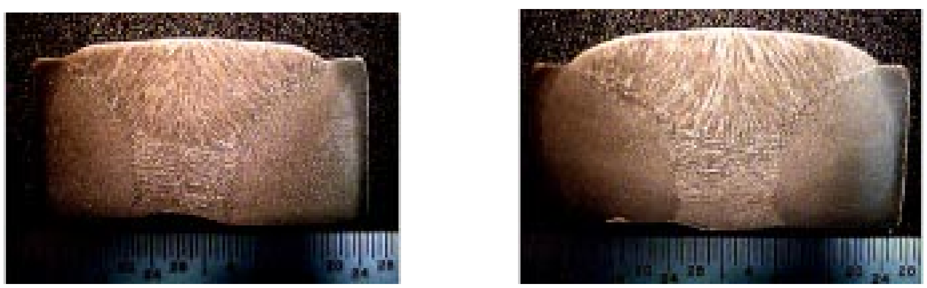
TABLE 4-2 MRF WELDING METHODS FOR ALTERNATIVE JOINT DESIGN

Procedure *Designation*	*Included* *Angle*	*Root* *Opening*	*Lead Arc [DCEN]* *(Amps / Volts)*	*Trail Arc [AC]* *(Amps / Volts)*	*Weld Angle* *(Lead / Trail)*
(AURL M1 – AUFH)	**30°**	**1/8" - 1/4"**	**700A / 23V**	**720A / 43V**	**0° / 15° (lead)**
(AURL M1 – AUFH M1)	**30°**	**1/8" - 1/4"**	**700A / 23V**	**770A / 48V**	**0° / 15° (lead)**

CONSUMABLES : Lincoln L-70 , 5/32" dia.; RF-1 Backing Flux; PFI-50 Welding Flux
WG-1 Iron Powder (Fill Height – 7/16" (50% of joint volume))

WELDING TECHNIQUE : Wire Extension [lead arc - 1 5/8" ; trail arc – 3 1/4"] Travel Speed – 15.6 ipm
Head Separation -- 4 inches Plate Thickness -- 11/16"

V.T. Inspection Results. (Test results from both procedure designations are presented in Task E, Table 1.2.1)
The macrospecimens cut at tackweld locations (Fig. 4-5) show the inconsistencies of weld root reinforcement penetration and contour.

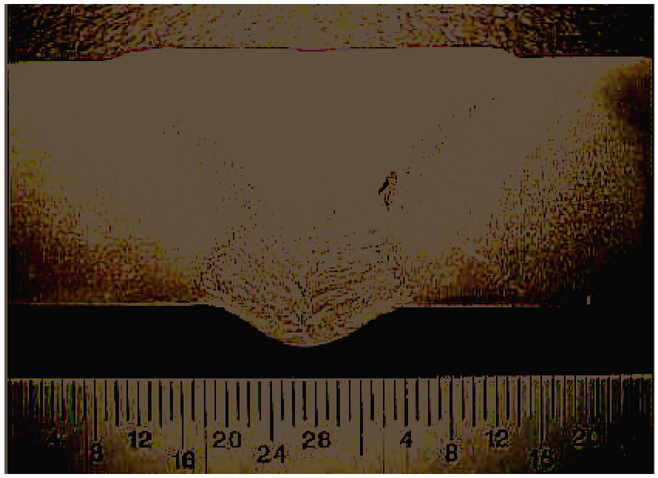


Test No. 187 -- Unacceptable Test No. 186 -- Acceptable
FIGURE 4-5 ROOT REINFORCEMENT AT TACKWELD LOCATIONS

V.T. inspections of the face reinforcement for each procedure designation are acceptable. The bead contours are smooth, free of spatter, undercut, overlap, and cracks. The reinforcement is adequate with a uniform contour and satisfies ABS visual inspection criteria.

U.T. Inspection Results. A high percentage of the test plates welded with both procedures have a short length of defect. Weld macrospecimens cut at U.T. failure locations reveal the common defect to be slag inclusions created by interbead lack-of-fusion. U.T. rejections are at random weld locations in the test joints with no relationship to tackwelds.

Photo-macro (Test # 10) illustrates this common interbead lack-of-fusion characteristic.



Test No. 10 -- Unacceptable

FIGURE 4-6 INTERBEAD LACK OF FUSION

Mechanical Test Properties.

Guided Side Bends -- Three of four guided sidebend specimens failed from Test No.35. Bend tests from Test I.D. W126 are acceptable.

FIGURE 4-7 Test I.D. 35 -- Specimen (2)

Impact Properties -- CVN impact test results (Test I.D. W126 & W177) are satisfactory with both procedures using DH-36 base metal. Impact test results in the HAZ (EH-36, Test I.D. W127 & 35) fail to meet minimum toughness requirements (see Tables 4-3 & 4-4) with the same two procedures.

Tensile Properties -- The tensile test results meet minimum ABS tensile strength requirements. The transverse tensile results (Test I.D. W126 & 35) are satisfactory for both procedures. The all weld metal tensile test (I.D. 35) properties are satisfactory (see Table 4-6).

CVN IMPACT TEST RESULTS FOR PROCEDURE DESIGNATION : AURL M1 - AUFH Impact Strength Rqmnt. -- 25 ft-lbs min. ABS RULES (1997) Table 2 / B.1.2 *(Test Temps.: 32 º F for DH-36 ; -4º F for EH-36)*			
BASE METAL (Test I.D.)	CVN IMPACTS @ C.L. (ft-lbs.) **Avg.**	CVN IMPACTS @ F.L. (ft-lbs.) **Avg.**	CVN IMPACTS @ 1.00mm HAZ (ft-lbs) **Avg.**
DH-36 (W126)	75.0 72.0 56.0 67.7	37.0 37.0 40.0 38.0	33.0 42.0 38.0 37.7
EH-36 (W127)	48.0 49.0 47.0 48.0	29.0 **22.0** 30.0 27.0	**14.0 11.0 10.0 11.7**

TABLE 4-3

CVN IMPACT TEST RESULTS FOR PROCEDURE DESIGNATION : AURL M1 - AUFH M1 Impact Strength Rqmnt. -- 25 ft-lbs min. ABS RULES (1997) Table 2 / B.1.2 *(Test Temps.: 32 º F for DH-36 ; -4º F for EH-36)*			
BASE METAL (Test I.D.)	CVN IMPACTS @ C.L. (ft-lbs) **Avg.**	CVN IMPACTS @ F.L. (ft-lbs) **Avg.**	CVN IMPACTS @ 1.00mm HAZ (ft-lbs) **Avg.**
DH-36 (W177)	30.0 41.0 30.0 33.7	46.0 41.0 **23.0** 36.7	**22.0** 43.0 **24.0** 29.7
EH-36 (35)	43.0 48.0 56.0 49.0	**18.0 16.0 18.0 17.3**	**18.0 16.0 22.0 18.7**

TABLE 4-4

TRANSVERSE WELD TENSILE PROPERTIES (Physical Testing conducted in accordance with ASTM E8-96) ABS RULES (1997) Table 2 / 1.2-2 Tensile Strength Requirements: 71 to 90 ksi	
BASE METAL (Test I.D.)	TENSILE STRENGTH (ksi)
DH-36 (W126)	77.0 – Acceptable 77.4 - Acceptable
EH-36 (35)	81.9 – Acceptable 82.4 - Acceptable

TABLE 4-5

ALL WELD METAL TENSILE PROPERTIES (Physical Testing conducted in accordance with ASTM E8-96) [ABS RULES (1997) Table 2 / B1.1 : Tensile Strength Requirement --71 to 95 ksi Yield Strength -- 54 ksi minimum]				
BASE METAL (Test I.D.)	YIELD STRENGTH (ksi)	TENSILE STRENGTH (ksi)	ELONGATION % /	REDUCTION OF AREA %
EH-36 (35)	79.8 – Acceptable	94.9 – Acceptable	22	36.1

TABLE 4-6

Summary of Preliminary Testing.

The results summarized below verify that additional modifications to the procedure developed in Task D are required before the procedure can be qualified.

(1) Consistent U.T. quality welds.

- In over 50% of the test plates there are locations of U.T. Rejections. The U.T. reject locations are scattered and typically do not exceed 25% of the joint length. This inconsistency is believed to be the cause of the side bend failures.

(2) CVN impact properties of the HAZ.

- Base material grade EH-36 test joints welded with both procedures have unacceptable CVN impact properties in the HAZ and the fusion line.

(3) V.T. rejections at tack weld locations

- Visual inspections reveal inconsistent root reinforcement at some of the tackweld locations.

Preliminary test results indicate that with a slight modification, procedure qualification is possible for base material grades, AH-36 and DH-36.

4.1.4 Further Procedure Development

Modifications to the optimal welding techniques are necessary to satisfy these objectives.

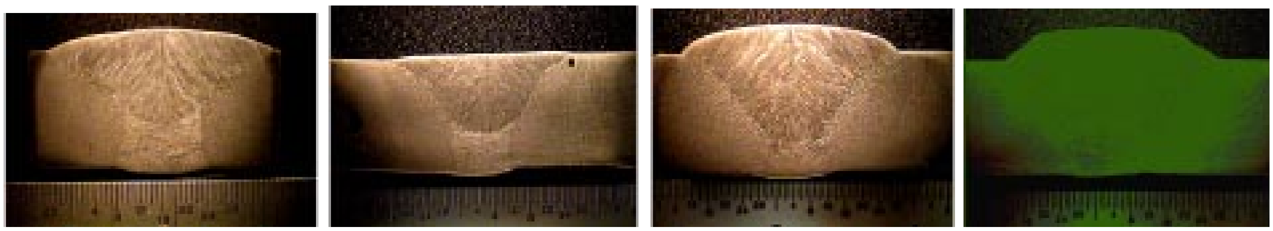
- Achieve consistent 100% interbead fusion (U.T. quality welds)
- Adequate root reinforcement at tack locations
- Improve HAZ CVN properties

Testing with Increased Trail Arc Wire Diameter. A trailing head with a wider/deeper penetrating arc can be obtained with a larger electrode diameter. The trailing arc wire diameter is increased from 5/32" to 3/16" for deep-penetration-type welds essential in achieving the goal of 100% interbead fusion. The lead arc parameters, joint design, and welding technique in these initial tests are unchanged.

V.T. Inspection of Surface Appearance and Macrostructure. This table presents measurements of trailing arc penetration at the respective amperage levels and the sequence of macros illustrates the expected effects that increased amperage have on depth of weld penetration. The weld penetration is compared with macro specimen No. 185 (Task D preliminary parameter settings) welded with the 5/32" diameter electrode.

TEST #	***ELECTRODE DIAMETER***	***TRAILING BEAD PENETRATION***	***LEAD (AMPS /VOLTS)***	***TRAIL (AMPS/VOLTS)***	***T.S. i.p.m.***	***ELECTRODE STICKOUT***
185	**5/32" / 5/32"**	13/32"	700A / 25V	770 A / 48 V	15.5	1 11/16" / 3-4"
40	**5/32" / 3/16"**	13/32"	700A / 25V	825A / 48V	15.5	1 11/16" / 3-4"
56	**5/32" / 3/16"**	17/32"	700A / 25V	900A / 48V	15.5	1 11/16" / 3-4"
53	**5/32" / 3/16"**	11/16"	700A / 25V	1000A / 48V	15.5	1 11/16" / 3-4"

TABLE 4-7



TEST No. 185
5/32" dia. Elec. @ 770A
(AURL M1 – AUFH M1)

TEST No. 40
3/16" dia. Elec. @ 825A

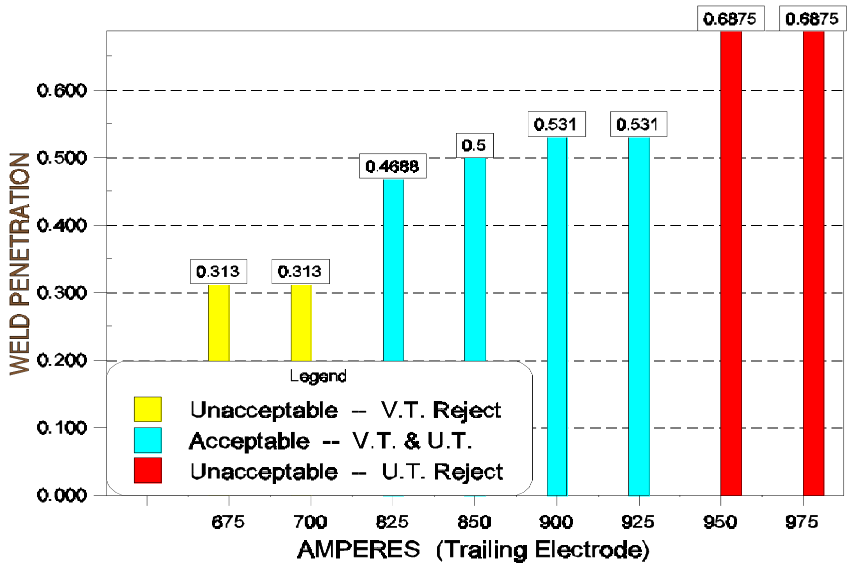
TEST No. 56
3/16" dia. Elec. @ 900A

TEST No. 53
3/16" dia. Elec. @ 1000A

FIGURE 4-8 TRAILING ARC WELD PENETRATION

The visual quality of the face reinforcement diminishes leaving poor inconsistent surface contour and lack of reinforcement with amperage settings below 800A. At amperage settings of 950A and higher, trailing bead melt-thru is evident creating unacceptable weld root contours.

U.T. Inspection Results. U.T. Inspection requirements are satisfied with amperage settings in the range of 850A to 950Amps. The higher end of this parameter range (900A – 930Amps) is preferred for the deep-penetration-type welds.



TEST NO.	(675A) 38	(700A) 39	(825A) 40	(850A) 41	(900A) 56	(925A) 43	(950A) 54	(975A) 61
V.T. RESULTS	**Reject**	**Reject**	**Accept.**	**Accept.**	**Accept.**	**Accept.**	**Reject**	**Reject**
U.T. RESULTS	----	----	**Accept.**	**Accept.**	**Accept.**	**Accept.**	**Reject**	**Reject**

TABLE 4-8

Trailing Arc Stickout Evaluation. A series of tests are welded using common parameter settings with stickout lengths of 1", 1 _", 2 _", 3 _", and 4" to evaluate the effects of trailhead wire stickout on weldability and interbead fusion characteristics.

Macro specimens are cut from five (5) locations of each test joint, at the weld start, weld end, and three (3) locations in between spaced equal distances apart. The five (5) weld penetration measurements of each test are averaged and results presented in the Table 4-9 by wire stickout length.

TRAIL HEAD		*STICKOUT LENGTHS*				
(930A / 48V)		1"	1 _"	2 _"	3 _"	4"
Weld Penetration	---	1/2"	9/16"	9/16"	9/16"	9/16"
Face Reinforcement	---	5/32"	1/8"	1/8"	1/8"	1/8"

TABLE 4-9

Test results of the weld penetration characteristics with this process show wire stickout length is not a major factor concerning weldability and penetration depth. The wire stickout length of 3 _" that is used in all of the previous tests is recommended.

Test No. 87 -- 1" WIRE STICKOUT Test No. 67 -- 3 1/4 " WIRE STICKOUT

FIGURE 4-9 PENETRATION CHARACTERISTICS WITH WIRE STICKOUT VARIATIONS

Mechanical Weld Properties. Three ABS grades of higher strength steel are included in these initial welding tests for comparison of mechanical properties using common parameters. Parameters (Table 4-10) selected for mechanical testing produce acceptable V.T. and U.T. results and they provide the best trailing arc penetration characteristics.

TEST No.	***BASE METAL GRADE***	***LEAD (AMPS /VOLTS)***	***TRAIL (AMPS/VOLTS)***	***T.S. i.p.m.***	***ELECTRODE STICKOUT***
83	AH-36	700A / 24V	930 A / 48 V	15.5	1 11/16" / 3 1/4"
91	EH-36	700A / 24V	930A / 48V	15.5	1 11/16" / 3 1/4"
92	DH-36	700A/ 24V	930A / 48V	15.5	1 11/16" / 3 1/4"

TABLE 4-10

The Transverse Tensile and All Weld Metal Tensile properties results of Test Numbers 83, 91, & 92 satisfy the minimum ABS strength requirements (see Tables 4-11 & 4-12).

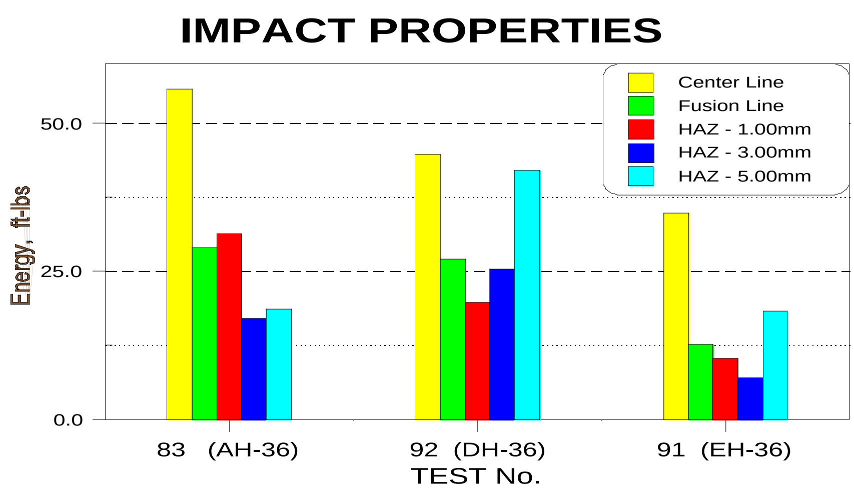
TRANSVERSE WELD TENSILE PROPERTIES **(Physical Testing conducted in accordance with ASTM E8-96)** **[ABS RULES (1997) Table 2 / 1.2-2 : Tensile Strength Requirement -- 71 to 90 ksi]**	
TEST No.	TENSILE STRENGTH (psi)
83	87,000 – Acceptable ; 87,000 – Acceptable
92	79,000 – Acceptable ; 79,000 – Acceptable
91	84,000 – Acceptable ; 84,500 – Acceptable

TABLE 4-11

ALL WELD METAL TENSILE PROPERTIES (**Physical Testing conducted in accordance with ASTM E8-96**) **[ABS RULES (1997) Table 2 / B1.1 : T.S. Rqmnt. -- 71 to 95 ksi Y.S. Rqmnt – 54 ksi minimum Elong. – 22% min.]**				
TEST No.	YIELD STRENGTH (psi)	TENSILE STRENGTH (psi)	ELONGATION %	REDUCTION OF AREA %
83	76,500 – Acceptable	98,500 – Acceptable	23.0 - Acceptable	55
92	81,000 – Acceptable	96,500 – Acceptable	26.0 - Acceptable	60
91	78,000 – Acceptable	96,500 – Acceptable	23.0 - Acceptable	62

TABLE 4-12

The CVN impact properties are acceptable at the weld centerline in all of the tests but the impact results in the HAZ are mixed, with each test failing in one or more locations. Test no.s 83 & 92 have satisfactory impact properties on the fusion line, but test no. 91 fails in this location because of the lower impact test temperature requirements for EH-36 higher strength steel (Table 4-14).



BASE MATERIAL	**AH-36**	**DH-36**	**EH-36**
TEST TEMPERATURE	**+ 68 F**	**+ 32 F**	**- 4 F**

TABLE 4-13

IMPACT TOUGHNESS PROPERTIES ***(CHARPY "V" NOTCH)*** **[ABS RULES (1997) Table 2 / B.1.2 ; Impact Strength Requirement -- 25 ft-lbs minimum]**							
TEST No.	WELD TEST TEMPERATURE	AVERAGE IMPACT STRENGTH (ft-lbs)					HEAT INPUT (Joules)
		CL	FL	1.00mm	3.00mm	5.00mm	
83	68 °F (20° C)	55.7	29.0	31.3	**17.0**	**18.7**	237,832
92	32 °F (0° C)	44.7	27.0	**19.7**	25.3	42.0	237,832
91	- 4 °F (-20° C)	34.7	**12.7**	**10.3**	**7.0**	**18.3**	237,832

TABLE 4-14

Achieving Adequate Root Reinforcement at Tack Locations. The root reinforcement at tack locations is inconsistent using the preliminary parameter settings. Approximately 50% of the tests welded are rejected visually because the tack locations do not have adequate root reinforcement.

Welding Parameter Evaluation. For improved root reinforcement it becomes necessary to increase the amperage of the lead arc. The macro graphs from test numbers 103, 104, and 105 illustrate the expected effects increasing amperage does have on root reinforcement and sidewall fusion in areas with tacks and without tacks (Table 4-15).

TYPICAL PROFILE OF ROOTWELD CROSS-SECTIONS

(T.S. – 15.5 ipm ELECTRODE STICKOUT – 1 11/16” TACKWELD SIZE – 3/16” x 1”)

LOCATION		***TEST # 103 (700A)***	***TEST # 104 (750A)***	***TEST # 105 (800A)***
(root reinforcement height)	---	1/16”	3/32”	5/32”
(root reinforcement @ tack)	---	0”	1/16”	3/32”
(sidewall fusion height)	---	15/32”	14/32”	12/32”

TABLE 4-15

Test No. 103 -- 700 Amps / 24 V Test No. 104 -- 750 Amps / 24V Test No. 105 -- 800 Amps / 24V

FIGURE 4-10 ROOT REINFORCEMENT AT NO TACKWELDS

The root reinforcement at tack locations is reduced approximately 1/16”.

Test No. 103 Test No. 104 Test No. 105

FIGURE 4-11 ROOT REINFORCEMENT AT TACKWELD LOCATIONS

The lead arc parameters of Test No. 104 (750A / 24V) provide acceptable root reinforcement characteristics through tack welds. Test No. 105 (800A / 24V) also provides improved root reinforcement but the reduced sidewall fusion height characteristics and the increased crown height (3/16”) make this weld susceptible to interbead lack-of-fusion.

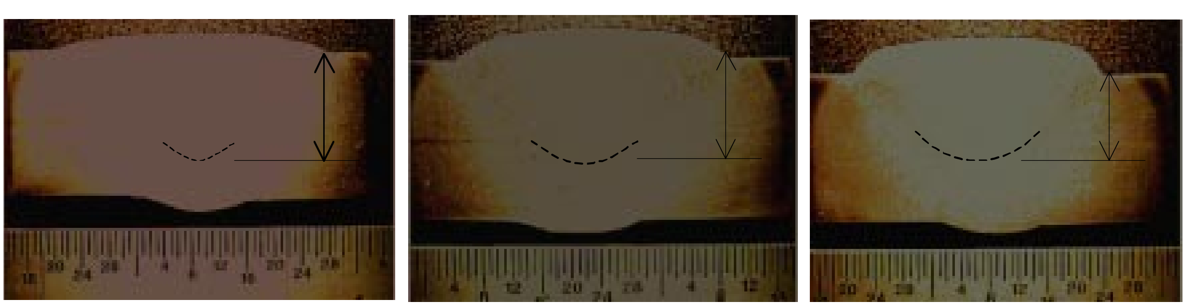
Evaluation of Tackweld Sizes on Root Reinforcement. Tack weld sizes that do not exceed 3/16” allow full SAW root weld penetration with adequate reinforcement. When tack sizes exceed 3/16”, the root reinforcement contour becomes rough and irregular. Oversize tacks effect the root weld penetration characteristics on both sides of the tack sometimes causing lack of reinforcement. The root side of tack welds are ground flush, regardless of size, to ensure root weld reinforcement that is uniform in size and contour. In Task F the adjusted parameters of WPS (NP-7A2.6E) allows full penetration welds through tacks (3/16” tack size) without the backside grinding requirement.

<u>Weldability Tests with Modified Trailing Arc Parameters</u>. The trailing arc weld parameters must be decreased in order to reduce overall heat input obtained with the initial parameter settings.

Decreasing Overall Heat Input. Initial welding tests indicate the acceptable trailing arc amperage range to be 850A to 950A (@ 48Volts). Although the amperages above 900A to 930A produce more favorable penetration characteristics, decreasing the trailing arc amperage below 900A is necessary to reduce the overall heat input. The trailing arc amperage is reduced to 850Amps and tested at three voltage settings in a range of 40V to 50 Volts. Each of these test assemblies meet the V.T. and U.T. quality Inspection Criteria.

TEST #	***LEAD (AMPS /VOLTS)***	***TRAIL (AMPS /VOLTS)***	***T.S. (i.p.m.)***	***ELECTODE STICKOUT***	***TRAILING ARC PENETRATION***	***U.T. INSPECTION***
123	**750A / 24 V**	**850A / 40 V**	**15.5**	**1 11/16” / 3 _”**	**9/16” (82% of joint th.)**	**Acceptable**
124	**750A / 24 V**	**850A / 45 V**	**15.5**	**1 11/16” / 3 _”**	**15/32” (68% of joint th.)**	**Acceptable**
125	**750A / 24 V**	**850A /50V**	**15.5**	**1 11/16” / 3 _”**	**13/32” (59% of joint th.)**	**Acceptable**

TABLE 4-16



Test No. 123 – 40 Volts Test No. 124 -- 45 Volts Test No. 125 -- 50 Volts

FIGURE 4-12 VOLTAGE AFFECTS TRAILING ARC WELD PENETRATION

Deeper weld penetration is achieved when voltage is reduced, but the sidewall fusion depth is reduced as macro specimen, Test No. 123 (Trail Head – 40V) illustrates, making the weldment more susceptible to lack of sidewall fusion.

Increased Travel Speed Settings. Increasing the travel speed is another parameter adjustment evaluated for reducing overall heat input. A series of tests performed at the travel speed of 18.0 ipm (increased from 15.5 ipm) satisfy both V.T. and U.T. Inspection requirements.

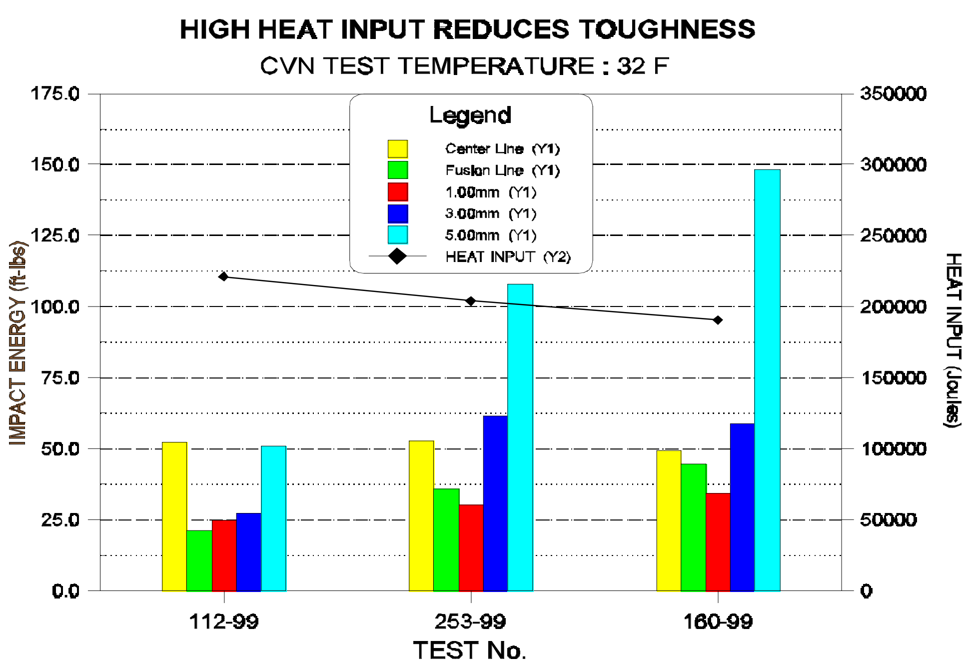
The trailing arc weld penetration levels are evaluated at two amperage settings in Test No. 160 (850A) and Test No. 253 (900A) at 18.0 ipm travel speed. The trailing arc penetration values are given in Table 4-17.

The overall heat input is reduced by 30,000 joules (approx. 14%) when the travel speed is increased from 15.5 ipm (Test No. 112) to 18.0 ipm (Test No. 160).

Mechanical Properties. Test No. 112, 160, and 253 are destructively tested to evaluate the mechanical properties. Base material in all of the tests is ABS Gr. DH-36.

TEST NO.	*LEAD ARC (AMPS /VOLTS)*	*TRAIL ARC (AMPS/VOLTS)*	*T.S. i.p.m.*	*ELECTRODE STICKOUT*	*HEAT INPUT*	*TRAILING ARC PENETRATION*
112	750A / 24 V	850A / 46V	15.5	1 11/16" / 3 _"	221,032 J	14/32" - 15/32"
160	750A / 24 V	850A / 46V	18.0	1 11/16" / 3 _"	190,333 J	14/32" - 15/32"
253	750A / 24 V	900A / 48V	18.0	1 11/16" / 3 _"	204,000 J	16/32"- 17/32"

TABLE 4-17



IMPACT TOUGHNESS PROPERTIES *(CHARPY "V" NOTCH)* **[ABS RULES (1997) Table 2 / B.1.2) : Impact Strength Requirement -- 25 ft-lbs minimum]**							
TEST No.	TEST TEMPERATURE	AVERAGE IMPACT STRENGTH (ft-lbs)					HEAT INPUT (Joules)
		CL	FL	1.00mm	3.00mm	5.00mm	
112	32^o F (0^o C)	52.3	21.0	24.7	27.3	51.0	221,032
253	32^o F (0^o C)	49.3	44.7	30.0	61.7	107.7	204,000
160	32^o F (0^o C)	52.7	36.0	34.3	58.7	148.3	190,333

TABLE 4-18

The Transverse tensile and All Weld Metal Tensile test properties are satisfactory and meet minimum ABS strength requirements.

FILLER METAL TENSILE PROPERTIES **(Physical Testing conducted in accordance with ASTM E8-96)** **[ABS RULES (1997) Table 2 / B1.1 : Tensile Strength Rqmnt. --71 to 95 ksi Yield Strength -- 54 ksi minimum Elong. -- 22% min.]**				
TEST No.	YIELD STRENGTH (psi)	TENSILE STRENGTH (psi)	ELONGATION %	REDUCTION OF AREA %
112	78,000 – Acceptable	94,500 – Acceptable	26.0 -- Acceptable	63
160	80,000 – Acceptable	93,000 – Acceptable	25.0 -- Acceptable	59
253	78,800 – Acceptable	94,900 – Acceptable	22.0 -- Acceptable	48

TABLE 4-19

TRANSVERSE WELD TENSILE PROPERTIES **(Physical Testing conducted in accordance with ASTM E8-96)** **[ABS RULES (1997) Table 2 / 1.2-2 : Tensile Strength Requirement -- 71 to 90 ksi]**	
TEST No.	TENSILE STRENGTH (psi)
112	78,500 – Acceptable ; 78,500 – Acceptable
160	79,000 – Acceptable ; 78,500 – Acceptable
253	81,529 – Acceptable ; 81,872 – Acceptable

TABLE 4-20

4.2 PROCEDURE / TECHNIQUE DEVELOPMENT -- 3/8" PLATE THICKNESS

4.2.1 Process Parameters

The optimum welding conditions established are presented in Table 4-21 for 0" to 1/4" root openings. V.T. and U.T. results are acceptable. Mechanical test results for tensile and yield strength are also acceptable. CVN weld metal toughness is acceptable for both DH-36 and EH-36, however the HAZ CVN toughness failed for EH-36.

Procedure development is initially performed with 3/8" test plate thickness with final testing done on 5/16" plate. A number of welding techniques are evaluated for various root openings to establish the optimum welding parameter settings. Tests with lower lead arc welding current (550A, 24.3V) and a travel speed of 20.3 ipm do not provide adequate root reinforcement in the tack weld locations (Task C). With parameter settings of procedure 1URL – 1UFL, adequate penetration and root reinforcement is achieved through tack welds (Table 4-21) and the overall visual weld characteristics are very good.

The only significant difference found in welding 3/8" plate thickness is with the amount of iron powder. No iron powder is required for root openings of 0" to 1/16". For root openings 1/8" through 1/4" the joint groove is completely filled with iron powder, level with the surface of the plate.

TABLE 4-21 WELDING CONDITIONS FOR 5/16" JOINTS

Procedure Designation	*Included Angle*	*Root Opening*	*Lead Arc [DCEN] (Amps / Volts)*	*Trail Arc [AC] (Amps / Volts)*	*Weld Angle (Lead / Trail)*
(1 URL – 1 UFL)	**45°**	**0" - 1/4" ***	**600A / 24.5V**	**400A / 38V**	**0° / 0°**

CONSUMABLES : Lincoln L-60, 5/32" dia.; RF-1 Backing Flux; PFI-50 Welding Flux
WG-1 Iron Powder (Fill Height – 100% of joint volume) (* - No Iron Powder used for 0"-1/16" root openings)

WELDING TECHNIQUE : Wire Extension [lead arc - 1 5/8" ; trail arc – 1 7/8"]; Travel Speed – 20.3 ipm
Head Separation – 4 inches

FIGURE 4-13 1/8" Root Opening

FIGURE 4-14 1/4" Root Opening

Mechanical Properties

IMPACT TOUGHNESS PROPERTIES — Impact Strength Requirement -- 25 ft-lbs minimum ABS RULES (1997) Table 2 / B.1.2 ; (*Test Temperatures: 32 º F for DH-36 & - 4º F for EH-36*)												
BASE METAL (Test I.D.)	CVN IMPACTS @ C.L. (ft-lbs)			**Avg.**	CVN IMPACTS @ F.L. (ft-lbs)			**Avg.**	CVN IMPACTS @ 1.00mm HAZ (ft-lbs)			**Avg.**
DH-36 (W55)	39.0	28.0	39.0	35.3	39.0	97.0	48.0	61.3	56.0	47.0	**15.0**	39.3
EH-36 (W56)	50.0	49.0	51.0	50.0	**10.0**	**10.0**	**13.0**	**11.0**	32.0	**16.0**	**15.0**	**21.0**

TABLE 4-22

TRANSVERSE WELD TENSILE PROPERTIES (Physical Testing conducted in accordance with ASTM E8-96) ABS RULES (1997) Table 2 / 1.2-2 Tensile Strength Requirements: EH-36 (71 to 90 ksi) ; Gr. A (58 to 75 ksi)		
BASE METAL (Test I.D.)	TENSILE STRENGTH (ksi) (1)	(2)
DH-36 (W55)	84.5k – Acceptable	81.2k – Acceptable
EH-36 (W56)	85.7k – Acceptable	84.6k – Acceptable

TABLE 4-23

4.3 PROCEDURE / TECHNIQUE DEVELOPMENT -- 1" PLATE THICKNESS

Joint designs with a 45º included V-groove are excluded from this evaluation because of the very large cross-sectional area. Comparing a 1" plate to a 11/16" plate with a 1/4" root opening, the volume of weld increases by more than 80%. It was concluded there was little possibility to weld the groove with this one-sided tandem arc process in a single pass. Instead a number of welding techniques were evaluated with various root openings and included angles of 20º and 30º.

Procedures explored for 20º included V-Grooves provide sufficient deposition rates to fill the groove and to form adequate face reinforcement for joint root openings of 1/8" to 5/16" but fail to provide acceptable face weld surface quality. Most of the procedures examined produce welds that are vulnerable to internal defects due to deep slag pockets developed in the root welds. Only two procedures developed in Task C, 3PR2-3PF4 and 3PR3-3PF4 provide adequate face weld penetration to prevent internal defects (Table 4-24). V.T. acceptance of the root and face welds are satisfactory for some of the welded joints with root openings of 1/8" to 1/4" but the results are not consistent.

TABLE 4-24 WELDING CONDITIONS FOR 1" JOINTS

Procedure <u>*Designation*</u>	*Included* <u>*Angle*</u>	*Root* <u>*Opening*</u>	*Lead Arc [DCEN]* <u>*(Amps / Volts)*</u>	*Trail Arc [AC]* <u>*(Amps / Volts)*</u>	*Weld Angle* <u>*(Lead / Trail)*</u>
(3 PR2 – 3 PF4)	**20^o**	**1/8" – 5/16"**	**800A / 23V**	**880A / 43V**	**0^o / + 15^o**
(3 PR3 – 3 PF4)	**20^o**	**1/8" – 5/16"**	**900A / 23V**	**880A / 43V**	**0^o / + 15^o**

CONSUMABLES : Lincoln L-70, 5/32" dia.; RF-1 Backing Flux; PFI-50 Welding Flux
WG-1 Iron Powder (Fill Height – 9/16" (50% of joint volume))
WELDING TECHNIQUE : Wire Extension [lead arc - 1 3/8" ; trail arc – 3 3/8"]; Travel Speed – 13.5 ipm

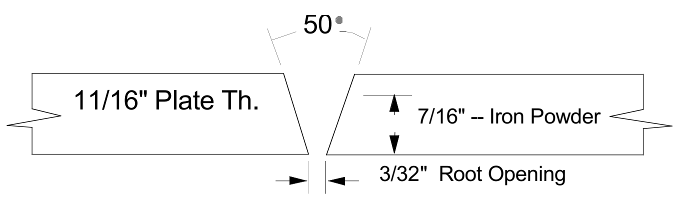
Procedure development for 1 inch plate thickness is the least successful. No reliable procedure has been developed that can produce adequate welds consistently, and without internal defects (interbead slag inclusions). Much of the testing effort is directed towards 11/16" plate. Information from extensive testing with 11/16" demonstrated that increasing development is required for 1" plate. Possibly a technique to explore is the addition of another electrode since the process is at the limit for HAZ properties with a tandem process.

4.4 ALTERNATIVE ONE-SIDED BACKING METHODS -- 11/16" PLATE THICKNESS

4.4.1 Various Procedures with Associated Backings

Hyundai Process -- This is a one-side welding method using soft and flexible backing material (S-22) that consists of fiberglass tape for forming the reverse bead and a corrugated card board pad for maintaining a uniform contact pressure which are wrapped in a moisture resistant thermo-shrinking film and also has double-side adhesive tape on the surface to make it easily settable to the reverse side of the groove.

Joint Design and Backing Method -- The Hyundai Weld Consumable publication provides the welding technique and parameter settings for this backing method.



SINGLE ARC (AMPS / VOLTS)	*CURRENT*	*T.S. i.p.m*	*ELECTRODE STICKOUT*	*HEAT INPUT*
950A / 40 V	**A.C.**	**8.0**	**1 9/16"**	**285,000 J**

TABLE 4-25

Welding Consumables

WIRE: Lincoln L-70, 3/16" dia. IRON POWDER: Pyron Powder WG-1 TOPSIDE FLUX: Kobe PFI-50

Surface Appearance and Macrostructure

V.T. Inspection -- The root and face weld reinforcement is acceptable. This fiberglass ceramic backing has very good bead forming characteristics with uniform height and contour.

U.T. Inspection Results -- Acceptable

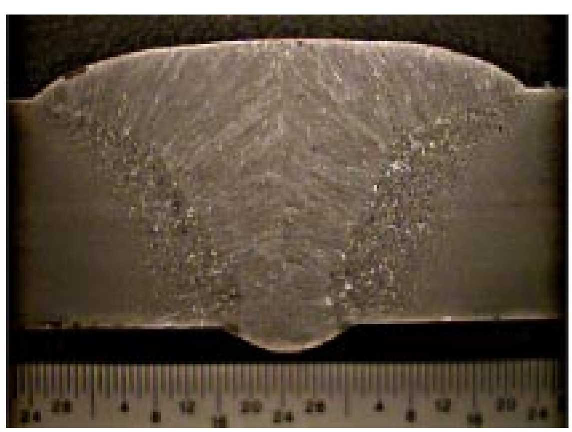
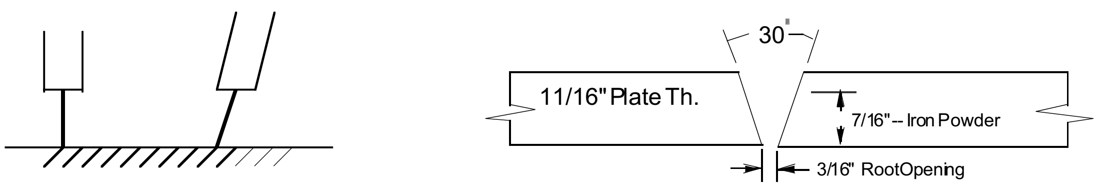


FIGURE 4-15 TEST No. 259

FAB-1 Process -- This is a one-side welding process using FAB-1 temporary backing material. FAB-1 has glass tape for special bead forming characteristics, solid flux for controlling the reverse bead height, a corrugated cardboard pad for uniform contact pressure and glass mat cushioning for obtaining good contact between two FAB-1 materials which are wrapped in a thermo-shrinking film.

Joint Design and Backing Method -- Welding Technique and parameter settings provided by Kobelco.

(Trail Head) (Lead Head – 5° lag angle)



LEAD ARC (AMPS /VOLTS)	*TRAIL ARC (AMPS /VOLTS)*	*CURRENT (LEAD / TRAIL)*	*T.S. i.p.m.*	*ELECTRODE STICKOUT*	*ELECTRODE SPACING*	*HEAT INPUT*
920A / 35 V	**600A / 30V**	**A.C. / A.C.**	**12.0**	**1 _" / 1 _"**	**3"**	**269,000 J**

TABLE 4-26

Welding Consumables

Lincoln L-70, 3/16" dia. (lead and trail arcs) IRON POWDER: Pyron Powder WG-1 TOPSIDE FLUX: Kobe PFI-50

Surface Appearance and Macrostructure

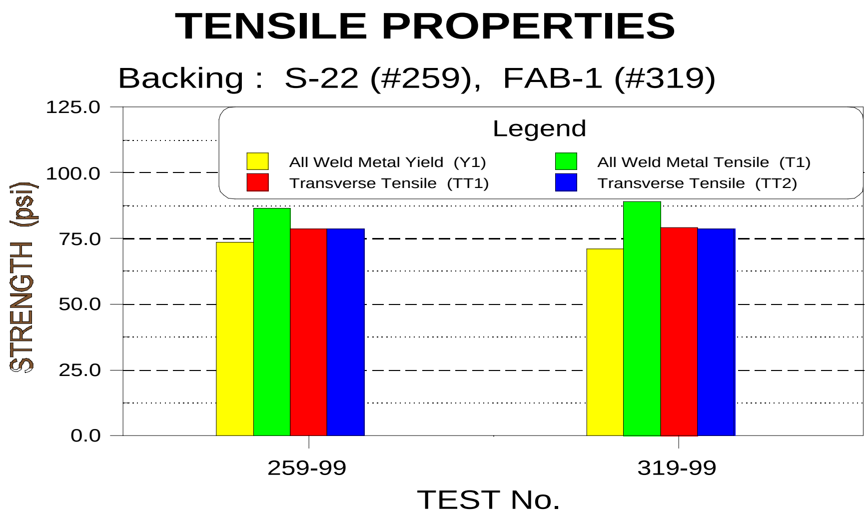
V.T. Inspection -- The cover pass reinforcement is adequate with a uniform surface contour, however the root weld contour is inconsistent with the FAB-1 process parameters and backing. The root reinforcement does not have a uniform surface contour and lack of reinforcement is a common problem.

U.T. Inspection Results -- Acceptable

FIGURE 4-16 TEST No. 319

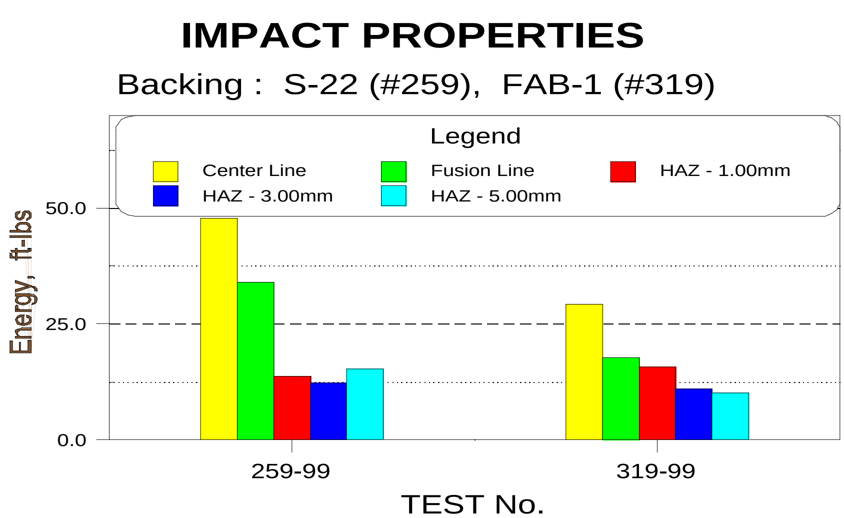
Mechanical Properties

The filler metal tensile and transverse weld tensile properties of both test joints are acceptable.



The tandem arc FAB-1 Process has unacceptable impact toughness properties (test no. 319) at the fusion line and Heat Affected Zones because of the extremely high heat input this process generates. The heat input generated with these parameters is 41% greater than the procedure qualified with the MRF Process.

Tests welded with the single arc Hyundai process parameters also have unacceptable impact toughness properties in the HAZ's because of excessive heat input. Approximately 36% greater than the procedure qualified parameters with the MRF Process.



FILLER METAL TENSILE PROPERTIES **(Physical Testing conducted in accordance with ASTM E8-96)** **[ABS RULES (1997) Table 2 / B1.1 : Tensile Strength Rqmnt. --71 to 95 ksi Yield Strength -- 54 ksi minimum Elong. -- 22% min.]**				
TEST No.	YIELD STRENGTH (psi)	TENSILE STRENGTH (psi)	ELONGATION %	REDUCTION OF AREA %
259	73,500 -- Acceptable	86,500 – Acceptable	26.0 -- Acceptable	62
319	71,000 -- Acceptable	89,000 – Acceptable	21.0 -- Acceptable	40

TABLE 4-27

TRANSVERSE WELD TENSILE PROPERTIES **(Physical Testing conducted in accordance with ASTM E8-96)** **[ABS RULES (1997) Table 2 / 1.2-2 : Tensile Strength Requirement -- 71 to 90 ksi]**	
TEST No.	TENSILE STRENGTH (psi)
259	79,000 – Acceptable ; 79,000 – Acceptable
319	78,500 – Acceptable ; 78,500 – Acceptable

TABLE 4-28

IMPACT TOUGHNESS PROPERTIES *(CHARPY "V" NOTCH)* **[ABS RULES (1997) Table 2 / B.1.2 : Impact Strength Requirement -- 25 ft-lbs minimum]** *(ABS Grade 2Y Filler Material)*						
TEST No.	TEST TEMPERATURE	AVERAGE IMPACT STRENGTH (ft-lbs)				
		CL	FL	1.00mm	3.00mm	5.00mm
259	32^{o} F (0^{o} C)	47.7	34.0	**13.7**	**12.3**	**15.3**
319	32^{o} F (0^{o} C)	29.3	17.7	15.7	11.0	10.0

TABLE 4-29

4.4.2 MRF Process Tested with Various Backings.

Manufacturers provided different forms of temporary backings that are evaluated with this one-side welding process using the MRF procedure qualified parameters with the same joint design and welding technique.

.

TEST NO.	*LEAD ARC (AMPS /VOLTS)*	*TRAIL ARC (AMPS/VOLTS)*	*T.S. i.p.m.*	*ELECTRODE STICKOUT*	*ELECTRODE SPACING*
160	**750A / 24 V**	**850A / 46V**	**18.0**	**1 11/16" / 3 _"**	**3 _"**

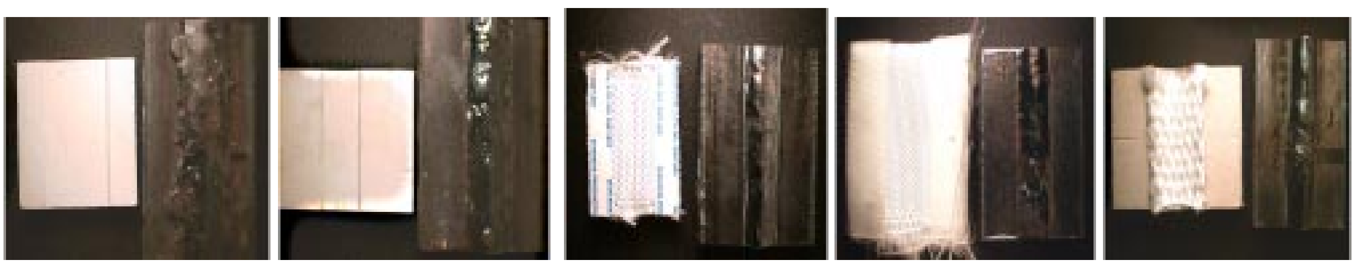
TABLE 4-30

Root pass V.T. Inspection results.

V.T. INSPECTION			
TEST No.	*BACKING TYPE*	*VISUAL RESULTS*	*WELDING CHARACTERISTICS*
44	Ceramic – large Square Channel	Unacceptable	Rough, irregular weld bead contour
47	Ceramic – small Square Channel	Unacceptable	Rough, irregular weld bead contour
78	Fiberglass tape w/ Refractory Backing	Acceptable	Adequate reinforcement, uniform surface contour
109	FAB –1 Backing	Unacceptable	Lack of reinforcement, irregular bead contour
352	Ceramic with Cloth Backing	Unacceptable	Excessive reinforcement, irregular bead contour

TABLE 4-31

The fiberglass tape with refractory backing (Test No. 78) provides excellent root weld bead forming characteristics similar to the MRF backing method.



TEST No.44 TEST No. 47 TEST No. 78 TEST No. 109 TEST No. 52

FIGURE 4-17 Various forms of backing materials

5.0 ABS APPROVAL

5.1 MRF PROCEDURE QUALIFICATION RECORD -- 11/16" PLATE THICKNESS

Testing includes visual and ultrasonic inspection, guided side-bends, transverse tensiles, all weld metal tensiles, and charpy V-Notch impacts at 5 locations in accordance with ABS Rules for Building and Classing Steel Vessels.

Based on previous testing and development the parameters of Test No. 160 were selected for procedure qualification. ABS approval of the Procedure Qualification Record was received December 03, 1999 and considered satisfactory. Comments received by ABS concerning this special welding application state that based upon test data submitted, this wire-flux combination Lincoln L-70 / Kobe PFI-50 plus Pyron powder is considered satisfactory for the intended application, to weld steels equivalent to ABS grade DH-36 and below.

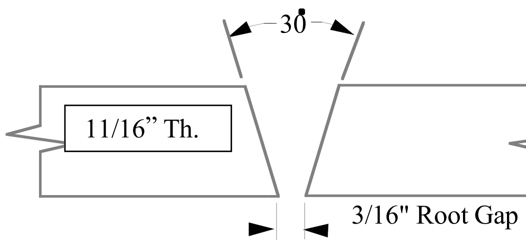
MRF -- PROCEDURE QUALIFICATION RECORD

Welding Process ___Submerged Arc (Modified Refractory Flux, One-Sided Welding)___

Power Source/s ___L-TEC VI-1200 CV (Lead Electrode) / Lincoln IdealArc AC-1200 (Trail Electrode)___

Control Boxes ___L-TEC UEC-8 (Lead Electrode) / Lincoln NA-4 (Trail Electrode)___

JOINT DESIGN B1V.3



BASE METALS

Type or Grade Tested __ABS Gr. DH-36__

Thickness Tested __11/16"__

Thickness Qualified (Mil.-248, see attach. A) _1/8" to 3 /4"_

Mil. Technical Manual -010/248 S-Group No. __S-1__

Material Specification __HSLA ASTM A537 – 1991 Cl. 1__

_Mil-S-22698 (SH) ; Grade DH-36 (Normalized) _(attach. C)

FILLER MATERIAL

Manufacturers Designation ___Lincoln L-70___

AWS Classif. / Spec. __EA 1-G / A5.23 (attach. D)__

Wire Size #1) __5/32"__ #2) __3/16"__

Type of Iron Powder ___Pyron Powder -- WG 1___

Powder Fill Level (with template) __7/16" (details on sheet 2)__

FLUX

Manufacturers Designation _KOBE PFI-50 (Top Side)_

Mesh Size ___10 x 48___

Backing Flux Type ___KOBE RF-1 (Root Side)___

Other ______

POSITION

Plate Position ___Flat (1G)___

ELECTRICAL CHARACTERISTICS

Electrode	#1	#2
Polarity	DCEN	AC
Amperage	750 A	850 A
Voltage	24V	46V
Travel Speed	18 ipm	
Heat Input	60,000 J	130,333 J

Overall Heat Input __190,333 Joules__

WELDING TECHNIQUE

Electrode	#1	#2
Work Angle	90°	90°
Lead Angle	0°	15° (push)
Elect. Stick Out	1-11/16"	3-1/4"
Elect. Spacing (in.)	4"	
Nozzle	**#1**	**#2**
Flux Tube Height	1-1/2"	2-1/8"

JOINT/PREWELD PREPARATION

Edge Preparation _15° Bevels (30° Included)_ _with a 3/16" root gap._

Base Material Cleaning _Grind or Wire Brush_ _joint bevels and top & bottom sides of plate surface_ _(1/2" minimum each side) to remove foreign matter._

Tackwelds _Grind convex bead profiles flush_ _with root side of joint._

MRF Backing Assembly _Aluminum_ _Trough (1-3/8" Radius) assembly instructions_ _shown on sheet 2._

PREHEAT

Preheat Temp. ___Ambient___

WELDING STANDARD NUMBER __NP-7A2.6__

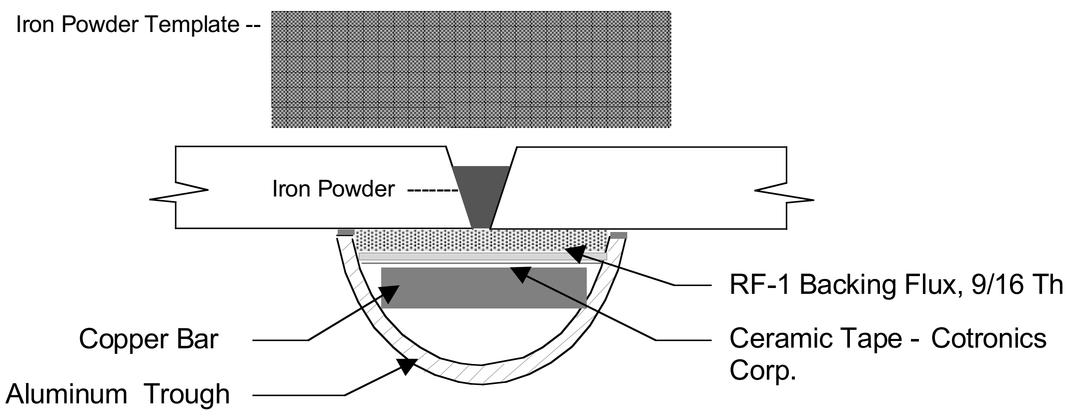
SHEET _1_ **of** _5_ **REVISION** _--_

--- WELDING TECHNIQUE SHEET ---

(PQR) NP- 7A2.6

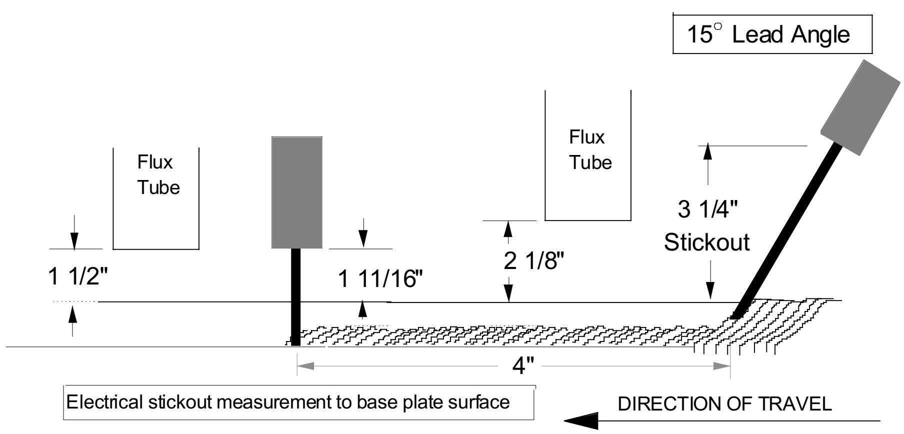
--- TROUGH ASSEMBLY ---

Attach side covers (masking tape) to both ends of the trough and fill assembly with RF-1 Backing Flux. Ensure the flux height is level with the top edges of the trough, then attach the back-up assembly to the joint with the magnetic clamps.



--- WELDING TECHNIQUE SHEET ---

SUBMERGED ARC - SINGLE PASS MRF				
LAYER No.	PASS No.	VOLTAGE	AMPERAGE	T.S. (ipm)
1	1	24V	750A	18.0
2	1	46V	850A	



WELDING PROCEDURE NUMBER NP-7A2.6	SHEET 02 OF 05	REVISION --

NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

Nondestructive Examinations conducted by: NASSCO, Quality Assurance, NDT Division

MIL-STD-2035, Class 1	Results
Visual Inspection	Acceptable

Destructive Tests Conducted by: Bodycote Materials Testing , Huntington Park, CA 90255
Laboratory Report Number: 07-21-NAV-098 / 094 / 247

GUIDED BEND TESTS (**Physical Testing conducted in accordance with ASTM E8-96**)			
Sample #1 - Acceptable	Sample #2 - Acceptable	Sample #3 - Acceptable	Sample #4 - Acceptable

FILLER METAL TENSILE PROPERTIES (**Physical Testing conducted in accordance with ASTM E8-96**)

[ABS RULES (1997) Table 2 / B1.1 : Tensile Strength Rqmnt. --71 to 95 ksi Yield Strength -- 54 ksi minimum Elong. -- 22% minimum]

ALL WELD TENSILE	DIMENSIONS	YIELD LOAD (lbs.)	TENSILE LOAD (lbs.)	YIELD STRENGTH (psi)	TENSILE STRENGTH (psi)	ELONG. %	REDUCTION OF AREA %
Longitudinal	.498	15,630	18,150	80,000 -- Accept.	93,000 – Accept.	25.0-Accept.	59.0

TRANSVERSE WELD TENSILE PROPERTIES (**Physical Testing conducted in accordance with ASTM E8-96**)

[ABS RULES (1997) Table 2 / 1.2-2 : Tensile Strength Requirement -- 71 to 90 ksi]

TRANSVERSE TENSILES	DIMENSIONS	TENSILE LOAD (lbs)	TENSILE STRENGTH (psi)	ELONGATION %	REDUCTION OF AREA %
#1 Fracture in Base	.498	15,375	79,000 -- Acceptable	------	------
#2 Fracture in Base	.498	15,330	78,500 -- Acceptable		

WELDING PROCEDURE NUMBER NP-7A2.6	SHEET 03 OF 05	REVISION --

NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

Destructive Tests Conducted by: Bodycote Materials Testing , Huntington Park, CA 90255
Laboratory Report Number: 07-07-NAV-247

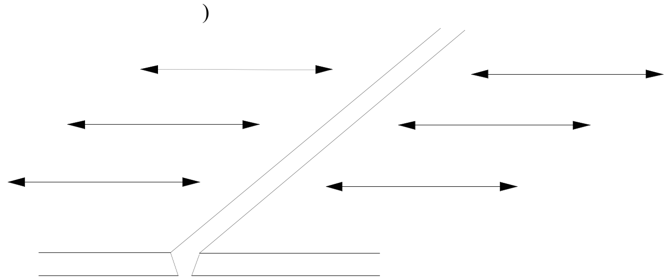
IMPACT TOUGHNESS PROPERTIES *(CHARPY "V" NOTCH)*

[ABS RULES (1997) Table 2 / B.1.2 *(ABS Grade 2Y Filler Material)* **: Impact Strength Requirement -- 25 ft-lbs minimum]**

SAMPLE I.D.	TEST TEMPERATURE	CHARPY IMPACT TEST RESULTS (ft-lbs)	LATERAL EXPANSION (in.s)	% SHEAR
Centerline # 1	32 ^{o} F (0^o C)	68.0	.053	65
Centerline # 2		38.0	.038	55
Centerline # 3		52.0	.046	60
		(Average CVN) 52.7 -- Acceptable		
Fusion line # 1	32 ^{o} F (0^o C)	48.0	.040	55
Fusion line # 2		25.0	.025	50
Fusion line # 3		35.0	.033	55
		(Average CVN) 36.0 -- Acceptable		
HAZ 1.00mm # 1	32 ^{o} F (0^o C)	32.0	.027	35
HAZ 1.00mm # 2		37.0	.028	35
HAZ 1.00mm # 3		34.0	.027	40
		(Average CVN) 34.3 -- Acceptable		
HAZ 3.00mm # 1	32 ^{o} F (0^o C)	93.0	.062	60
HAZ 3.00mm # 2		39.0	.032	65
HAZ 3.00mm # 3		44.0	.036	60
		(Average CVN) 58.7 -- Acceptable		
HAZ 5.00mm # 1	32 ^{o} F (0^o C)	124.0	.086	75
HAZ 5.00mm # 2		163.0	.092	25
HAZ 5.00mm # 3		158.0	.092	20
		(Average CVN) 148.3 -- Acceptable		

--- PLATE ROLLING DIRECTION ---

(TRANSVERSE TO WELD SEAM)



WELDING PROCEDURE NUMBER NP-7A2.6	SHEET 04 OF 05	REVISION --

NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

We certify that the statements in this record are correct and the procedure satisfies the Military Technical Manual -010/248 requirements and is in accordance with ABS Rules for Building Steel Vessels, Part 2 Section 3.C.5.4 (1997).

Prepared by : _Randy Doerksen, Assistant Welding Engineer__ Date : _November 08, 1999 _

Approved by : _Michael J. Sullivan, Chief Welding Engineer__ Date : __November 08, 1999_

- Test Reports are maintained on file by Welding Engineering

--- ATTACHMENTS ---

A) S9074-AQ-GIB-010 / 248 - Welding PQR Material Thickness Limits

B) Mechanical Testing Report - Bodycote Materials Testing
ABS Tensile & Impact Test Requirements

C) Base Material Certifications - 11/16" HSLA Plate Gr. DH-36
Application of filler metals to ABS Steels

D) Certified Filler Metal Test Reports - Lincoln 5/32" & 3/16" L-70 Electrode
ABS Wire-Flux Combination
KOBI PFI-50 (top) Flux (MSDS)
KOBI RF-1 Backing Flux (MSDS)
Pyron Iron Powder (Certificate & MSDS)

E) NASSCO - V.T. Inspection Report
U.T. Inspection Report

WELDING PROCEDURE NUMBER NP-7A2.6	SHEET 05 OF 05	REVISION --

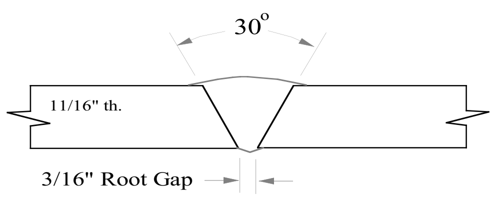
6.0 PRODUCTION AND DEMONSTRATION WELDING

6.1 MODIFICATIONS TO PQR

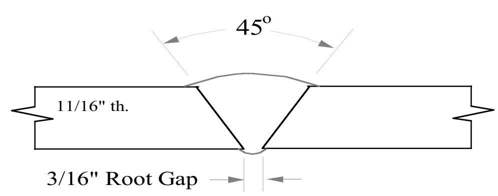
6.1.1 Erection Joint Design

The MRF welding procedure is qualified with a 30^{o} included single V-Groove joint design. Due to changes in neat erection policy at NASSCO, weld joints were prepared in fabrication within the joint design to suit NASSCO's current process. This did not allow changes in bevel preparation in a timely manner to suit this project's schedule for production testing. As a result, changes are made to WPS to account for an increase in bevel angle.

PROCEDURE QUALIFIED JOINT DESIGN



ERECTION JOINT DESIGN



Weight of Weld Metal : 1.03 lbs/ft 1.28 lbs/ft

Parameter Adjustments. Welding parameters are increased within the limits of the procedure qualification to accommodate the joint geometry for this single pass process. Initial erection joint design tests produce satisfactory visual characteristics and sidebend test results are acceptable.

Procedure		*Included Angle*	*Lead Arc (Amps / Volts)*	*Trail Arc (Amps / Volts)*	*T. S. (ipm)*	*Stickout (Lead / Trail)*
NP-7A2.6 (PQR)	**---**	**30**	**750A / 24V**	**850A / 46V**	**18**	**1 11/16" / 3 _"**
NP-7A2.6C (WPS)	**---**	**45**	**750A / 26V**	**950A / 50V**	**18**	**1 11/16" / 3 _"**
NP-7A2.6E (WPS)	**---**	**45**	**750A / 28V**	**900A / 48V**	**18**	**1 11/16" / 3 _"**

TABLE 6-1

Comparison of weld cross-section macro-photos from the procedure qualification joint (Test No.160) and erection joint design test (No. 397) illustrate the fusion characteristics obtained with these parameter adjustments required for this modified joint design.

3/16" ROOT GAP / 30^{o} INCLUDED V-GROOVE

FIGURE 6-1 TEST NO. 160 (PQR) NP-7A2.6

3/16" ROOT GAP / 45^{o} INCLUDED V-GROOVE

FIGURE 6-2 TEST NO. 397 (WPS) NP-7A2.6C

NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

Welding Procedure Specification (WPS) NP-7A2.6C **Date: JANUARY 2000**

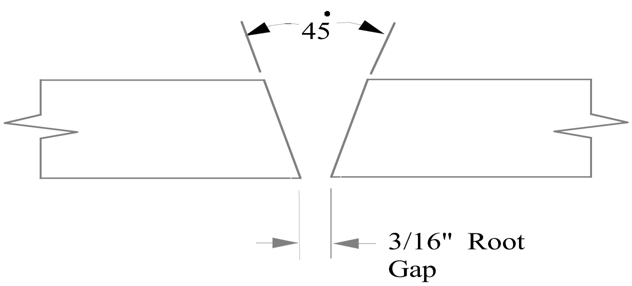
Associated Procedure Qualification Record No. (PQR) NP-7A2.6

Welding Process Submerged Arc (Single Pass One Sided Welding)

Power Source/s L-TEC VI-1200 CV (Lead Electrode) / Lincoln IdealArc AC-1200 (Trail Electrode) .

Control Boxes L-TEC UEC-8 (Lead Electrode) / Lincoln NA-4 (Trail Electrode)

JOINT DESIGN B1V.3



BASE METALS

Type or Grade Tested ABS Gr. DH-36
Thickness Tested 11/16"
Mil. Technical Manual -010/248 S-Group No. S-1
Material Specification HSLA ASTM A537 – 1991 Cl 1
Mil-S-22698 (SH) ; Grade DH-36 (Normalized) (attach. C)

FILLER MATERIAL

Manufacturers Designation Lincoln L-70
AWS Class. / Spec. EA 1-G / A5.23 (attach. D)
Wire Size #1) 5/32" #2) 3/16"
Type of Iron Powder Pyron Powder -- WG 1
Powder Fill Level (with template) 7/16" (details on sheet 2)

FLUX

Manufacturers Designation KOBE PFI-50 (Top Side)
Mesh Size 10 x 48
Backing Flux Type KOBE RF-1 (Root Side)
Other

POSITION

Plate Position Flat (1G)

ELECTRICAL CHARACTERISTICS

Electrode	#1	#2
Polarity	DCEN	AC
Amperage	750 A	950A
Voltage	26 V	50V
Travel Speed	18 ipm	

WELDING TECHNIQUE

Electrode	#1	#2
Work Angle	90°	90°
Lead Angle	0°	15° (push)
Elect. Stick Out	1-11/16"	3-1/4"
Elect. Spacing (in.)	4"	

Nozzle	#1	#2
Flux Tube Height	1-1/2"	2-1/8"

JOINT/PREWELD PREPARATION

Edge Preparation 22.5° Bevels (45° Included) with a 3/16" root gap.

Base Material Cleaning Grind or Wire Brush joint bevels and top & bottom sides of plate surface (1/2" minimum each side) to remove foreign matter.

Tack welds Grind convex bead profiles flush with root side of joint.

Backing Method MRF

PREHEAT

Preheat Temp. Ambient (Remove Moisture)

WELDING STANDARD NUMBER NP-7A2.6 **SHEET 1 of 2** **REVISION --**

6.2 ERECTION JOINTS WELDED WITH QUALIFIED MRF PROCESS

6.2.1 Longitudinal Deck Seams -- (WPS) NP-7A2.6C

The visual inspection results and repair welding requirements are described for all of the erection seams welded (six) with (WPS) NP-7A2.6C parameters.

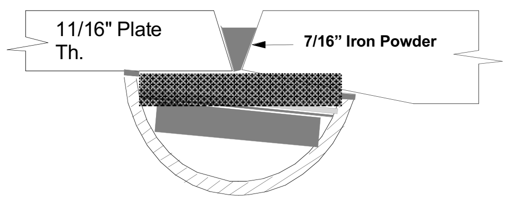
Procedure	Included Angle	Lead Arc (Amps / Volts)	Trail Arc (Amps / Volts)	T. S. (ipm)	Stickout (Lead / Trail)
NP-7A2.6C (WPS) ---	**45º**	**750A / 26V**	**950A / 50V**	**18**	**1 11/16" / 3 _"**

TABLE 6-2

"C" DECK BLOCKS 231 / 232

Date Welded -- January 31, 2000

Joint Groove Preparation -- Centerline seam plate sizes are 11/16" & 1 _" thickness with the thicker plate prepared with a 4 to 1 chamfer. The joint root opening is 1/8" to 3/16".



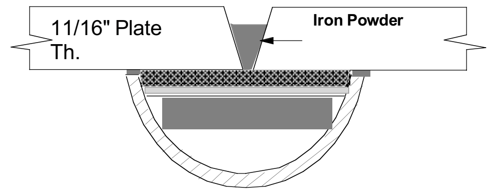
Visual Inspection Results -- Weld root reinforcement is acceptable (0" to 3/32") with the MRF backing providing adequate support for this 4 to 1 joint chamfer design. The copper bar seated inside the trough was not level, however the RF-1 backing still provides adequate flux support under the joint root opening to prevent melt-through. The face reinforcement and surface contour (0" to 1/8") are acceptable.

Another backing material evaluated in Phase E with successful results is used on a section of this production seam. This backing consists of a ceramic material with a fiberglass cloth covering. Visual inspection results are unacceptable because of excessive root reinforcement caused by the poor fitting characteristics of the flat tape against the chamfered surface.

Blocks 231 / 232 -- Trough Assembly
FIGURE 6-3

Blocks 231 / 232 -- MRF Root Reinforcement
FIGURE 6-4

"B" DECK BLOCKS 351 / 291 **Date Welded -- February 15, 2000**



Joint Groove Preparation -- The joint root opening ranges from 0" to 1/8" with an included angle of 40 ^{o} to 45^{o}.

Visual Inspection Results -- The face reinforcement is adequate (3/16" to 1/4"). The root weld contour is satisfactory with the MRF backing material, but 12 ft. of irregular bead contour is rejected in an area with fiberglass covered ceramic backing and a 0" root opening. The operator must monitor electrode alignment with the joint centerline and be ready to correct electrode offsets from the joint centerline caused by inconsistent root openings or joint asymmetry. The root reinforcement is 3/32" to 1/8".

Repair Description -- Irregular root weld contour required grinding and additional weld root passes.

MRF Root Reinforcement -- Blocks 351 / 291
FIGURE 6-5

MRF Face Reinforcement -- Blocks 351 / 291
FIGURE 6-6

"C" DECK BLOCKS 242 / 244 **Date Welded -- March 14, 2000**

Joint Groove Preparation -- The root opening ranges from 0" to 3/16" with an included angle of 40 ^{o}.

Visual Inspection Results -- Ten feet of this joints root reinforcement is irregular and some locations do not have adequate root reinforcement. Poor weld penetration persisted in locations with a 0" root opening. The weld face reinforcement and contour are acceptable.

Repair Description -- Areas with lack of weld penetration required root side arc gouging to sound metal before grinding and repair welding.

"C" DECK BLOCKS 246/ 248 **Date Welded -- March 15, 2000**

Joint Groove Preparation -- The root opening ranges from 0" to 1/8" and the included angle was 40^{o} to 45^{o}.

Visual Inspection Results -- Approximately 90% (50ft) of this joint's root weld does not have adequate root reinforcement caused by electrode offset from the joint centerline. Face reinforcement and contour are acceptable.

Repair Description -- The joint's entire rejected length (lack of root penetration) is arc gouged to clean metal and prepared by grinding before weld repair.

"C" DECK BLOCKS 241 / 243 **Date Welded -- March 17, 2000**

Joint Groove Preparation -- The joint root opening ranges from 0" to 1/16" and the included angle is 37^{o} to 40^{o}.

Visual Inspection Results -- Approximately 15 ft. of this joint's root reinforcement has an unacceptable weld bead contour. The Electrodes alignment with the joint centerline is critical to adequate root penetration with reduced bevel angles and 0" root openings. Face reinforcement and bead contour are acceptable.

Repair Description -- The rejected areas with weld rollover are repaired by grinding and additional root weld passes to correct the irregular bead contour.

MRF Face Reinforcement -- Blocks 241 / 243

FIGURE 6-7

"C" DECK BLOCKS 245 / 247 **Date Welded -- March 20, 2000**

Joint Groove Preparation -- The root opening ranges from 0" to 1/16" and the included angle is 40^{o} to 45^{o}.

Visual Inspection Results -- Approximately 40 ft. of this joint's root reinforcement is acceptable and the remaining length (15 ft.) has an irregular bead contour. Joint asymmetry and tight root opening are considered to be the contributing factors for this rejected length and a means of correction is reviewed in the next section. The face reinforcement and contour are acceptable.

Repair Description -- Additional grinding and root passes are required to correct irregular bead contour and weld rollover condition.

Observations. The visual quality of the face reinforcement is satisfactory for all of the seams, but the visual root inspection reveals areas with irregular bead contour and lack of weld penetration.

V.T. and U.T. Inspection requirements in accordance with ABS Rules for Building Steel Vessels, Part 2.

PROCEDURE : ***(WPS) NP-7A2.6C***

Block No.:	231 / 232	351 / 291	242 / 244	246 / 248	241 / 243	245 / 247
Date of Welding :	Jan 31, '00	Feb 15, '00	Mar 14, '00	Mar 15, '00	Mar 17, '00	Mar 20, '00

JOINT PREPARATION [Joint Design -- 45° Included V-Groove with 0 to 3/16" root opening]

Root Opening :	1/8" - 3/16"	0" – 1/8"	0" – 3/16"	0" – 1/8"	0" – 1/16"	0" – 1/16"
Included Angle :	45°	40° - 45°	40°	40° - 45°	37° - 40°	40° - 45°

VISUAL INSPECTION

Face Reinforcement:	Acceptable	Acceptable (40ft.)	Acceptable (40ft.)	Acceptable (56ft.)	Acceptable (40ft.)	Acceptable (55ft.)
Root Reinforcement:	Acceptable*	Acceptable (28ft.) *	Acceptable(30ft.) *	Acceptable (6ft.)	Acceptable (25ft.)	Acceptable (40ft.)
[Unacceptable Length]		[12 ft.]	[10 ft.]	[50 ft.]	[15 ft.]	[15 ft.]

* MRF Backing – Root Pass Acceptable

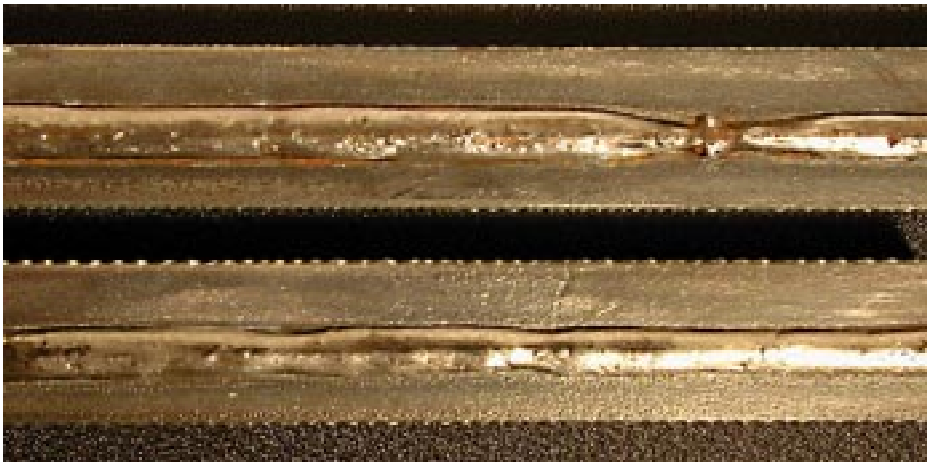
ULTRASONIC INSPECTION

Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Ultrasonic Test Inspection Results (10% of joint length, random locations)

Electrode positioning adjustments to the joint centerline during welding is critical. The operator used a pointer mounted on the gun head assembly as a joint centerline tracking method. This tracking aid alone did not provide assurance of accurate electrode positioning (Blocks 246/248) on the centerline because the head assembly was inadvertently bumped by the operator and not aligned before welding. Another joint tracking aid consisting of a neon laser light is attached to the carriage as a backup method of verifying electrode alignment. Test joints are prepared to simulate typical erection seam conditions with 40° included V-grooves, 0" root openings and the joints declivity of 4° to determine if typical production conditions are responsible for the poor penetration characteristics and irregular bead contours observed in the root passes of these erection seams.

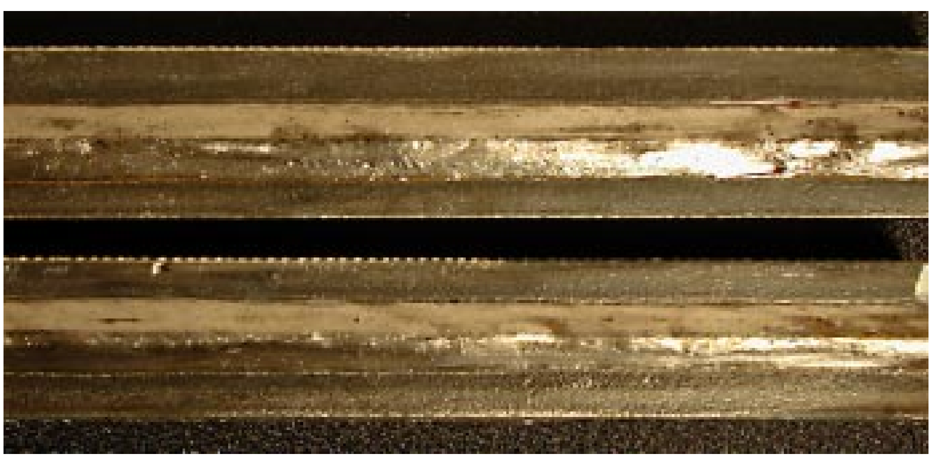
Test plates are welded in accordance with (WPS) NP-7A2.6C. Poor root penetration (Test No. 427), weld rollover and irregular bead contour (Test No. 430) duplicate the typical defects identified in the root passes of erection seams.



Test No. 427 (top) ; Test No. 430 (bottom)

FIGURE 6-8 Root Welds with Poor Reinforcement and Rollover.

Welding parameters are modified to improve the root weld penetration characteristics. Test No. 434, 435 and 439 are also prepared to simulate typical erection conditions. The welding voltage is increased from 26V to 28Volts (750A) and the iron powder level is adjusted from 7/16" to a 3/8" fill height. Adequate root reinforcement is achieved and sidebend test (No. 439) results are acceptable.



Test No. 435 (top) ; Test No. 434 (bottom)

FIGURE 6-9 Root Weld Parameters -- 750A / 28V

This macro-etch specimen cut from Test No. 439 is welded with the increased voltage. The face reinforcement has a crown shape profile tapering down at the toes of the weld unlike the profile seen with joints welded in the flat position but resembling the face reinforcement of the erection seams welded.

INCLUDED V-GROOVE	--	40°
ROOT OPENING	--	0”
JOINT INCLINE	--	4°

Face Reinforcement Profile, Test No. 439

FIGURE 6-10

The next set of production seams are welded with the modified parameters of (WPS) NP-7A2.6E.

NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

Welding Procedure Specification (WPS) NP-7A2.6E **Date: JANUARY 2000**

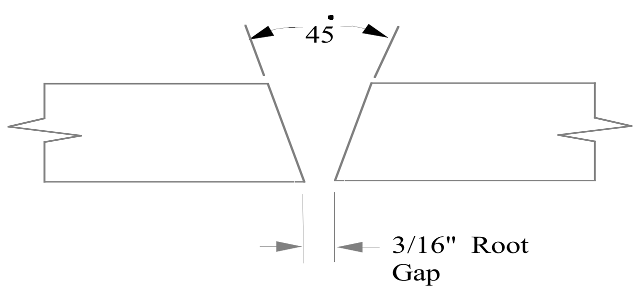
Associated Procedure Qualification Record No. (PQR) NP-7A2.6

Welding Process Submerged Arc (Single Pass One Sided Welding)

Power Source/s L-TEC VI-1200 CV (Lead Electrode) / Lincoln IdealArc AC-1200 (Trail Electrode)

Control Boxes L-TEC UEC-8 (Lead Electrode) / Lincoln NA-4 (Trail Electrode

JOINT DESIGN B1V.3



BASE METALS

Type or Grade Tested ABS Gr. DH-36
Thickness Tested 11/16"
Mil. Technical Manual -010/248 S-Group No. S-1
Material Specification HSLA ASTM A537 – 1991 Cl. 1
Mil-S-22698 (SH) ; Grade DH-36 (Normalized) (attach. C)

FILLER MATERIAL

Manufacturers Designation Lincoln L-70
AWS Class. / Spec. EA 1-G / A5.23 (attach. D)
Wire Size #1) 5/32" #2) 3/16”
Type of Iron Powder Pyron Powder -- WG 1
Powder Fill Level (with template) 3/8” -7/16" (details on sheet 2)

FLUX

Manufacturers Designation KOBE PFI-50 (Top Side)
Mesh Size 10 x 48
Backing Flux Type KOBE RF-1 (Root Side)
Other

POSITION

Plate Position Flat (1G)

ELECTRICAL CHARACTERISTICS

Electrode	#1	#2
Polarity	DCEN	AC
Amperage	750 A	900A
Voltage	28 V	48V
Travel Speed	18 ipm	

WELDING TECHNIQUE

Electrode	#1	#2
Work Angle	90°	90°
Lead Angle	0°	15° (push)
Elect. Stick Out	1-11/16"	3-1/4”
Elect. Spacing (in.)	4"	

Nozzle	#1	#2
Flux Tube Height	1-1/2"	2-1/8"

JOINT/PREWELD PREPARATION

Edge Preparation 22.5° Bevels (45° Included) with a 3/16” root gap.

Base Material Cleaning Grind or Wire Brush joint bevels and top & bottom sides of plate surface (1/2” minimum each side) to remove foreign matter .

Tack welds Grind convex bead profiles flush with root side of joint.

Backing Method MRF

PREHEAT

Preheat Temp. Ambient (Remove Moisture)

WELDING STANDARD NUMBER NP-7A2.6 **SHEET 1 of 2 REVISION --**

6.2.2 Longitudinal Deck Seams -- (WPS) NP-7A2.6E

The next four (4) erection seams are welded with the modified root weld parameters and a 3/8" iron powder fill level.

Procedure	*Included Angle*	*Lead Arc (Amps / Volts)*	*Trail Arc (Amps / Volts)*	*T. S. (ipm)*	*Stickout (Lead / Trail)*
NP-7A2.6E (WPS) ---	**45º**	**750A / 28V**	**900A / 48V**	**18**	**1 11/16" / 3 _"**

TABLE 6-3

"B" DECK BLOCKS 313 / 395 **Date Welded -- May 03, 2000**

Joint Groove Preparation -- The joint root opening ranges from 0" to 3/16" and the included angle is 40° to 45°.

Visual Inspection Results – Weld rollover is identified in 12 feet of root reinforcement, caused by plate misalignment up to 1/8" in the fiberglass/ceramic backing section. The face reinforcement is acceptable.

Repair Description -- Additional grinding and weld passes are required to correct bead rollover.

"B" DECK BLOCKS 315 / 399 **Date Welded -- May 05, 2000**

Joint Groove Preparation -- The joint root opening ranges from 0" to 1/4" and the included angle is 40° to 45°.

Visual Inspection Results – The root weld has acceptable root reinforcement. Almost 20 ft. of the joint requires additional cover passes (top side) because the root opening (>3/16") caused underfill.

MRF Root Reinforcement -- Blocks 315 / 399

FIGURE 6-11

MRF Face Reinforcement -- Blocks 313 / 395

FIGURE 6-12

"B" DECK BLOCKS 314 / 396 **Date Welded -- May 08, 2000**

Joint Groove Preparation -- The joint root opening ranges from 0" to 1/8" and the included angle is 40° to 45°.

Visual Inspection Results -- Four feet of weld root repair required to correct the weld rollover condition caused by plate misalignment of 1/16" to 1/8" in the area of cloth tape. The face reinforcement and weld contour are acceptable.

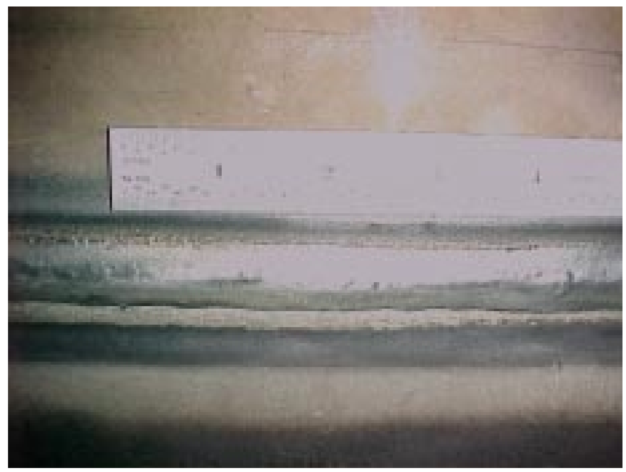
Repair Description -- Grinding and additional welding passes are required to repair root weld rollover.

"B" DECK BLOCKS 314 / 400 **Date Welded -- May 09, 2000**

Joint Groove Preparation -- The joint root opening ranges from 0" to 5/32" and the included angle is 40° to 45°.

Visual Inspection Results -- The root and face reinforcement are visually acceptable.

Root Reinforcement -- Blocks 314 / 396
FIGURE 6-13



Root Reinforcement -- Blocks 314 / 396
FIGURE 6-14

Face Reinforcement -- Blocks 314 / 400
FIGURE 6-15

Root Reinforcement -- Blocks 314 / 400
FIGURE 6-16

Observations. The root reinforcement repair hours are significantly reduced with the modified lead arc parameters (750A, 28V) which produce improved weld penetration characteristics. Two seams each have one location of weld rollover in joint areas of plate misalignment (1/16 to 1/8") with the fiberglass cloth covered ceramic backing material. This condition occurs as the heat of the process melts a tack weld, adjacent tacks may crack because other restraining forces on the joint are too great, causing plate misalignment.

PROCEDURE : ***(WPS) NP-7A2.6E***

Block No.:	313 / 395	315 / 399	314 / 396	314 / 400
Date of Welding :	May 3, '00	May 5, '00	May 8, '00	May 9, '00

JOINT PREPARATION [Joint Design -- 45° Included V-Groove with 0 to 3/16" root opening]

Root Opening :	0" - 3/16"	0" – 1/4"	0" – 1/8"	0" – 5/32"
Included Angle :	40° - 45°	40° - 45°	40° - 45°	40° - 45°

VISUAL INSPECTION

Face Reinforcement :	Acceptable (45ft.)	Acceptable (26ft.)	Acceptable (44ft.)	Acceptable (40ft.)
[Unacceptable Length]		[20 ft.]		
Root Reinforcement :	Acceptable (33 ft.)	Acceptable (46ft.)	Acceptable (40 ft.)	Acceptable (40ft.)
[Unacceptable Length]	[12 ft.]		[4 ft.]	

ULTRASONIC INSPECTION

	Acceptable	Acceptable	Acceptable	Acceptable

Test No. 440 is fit with an excessive root opening to duplicate the conditions and joint design of "B" Deck Blocks 315/399. The macro-specimen shows the typical face weld profile of this joint with root openings exceeding 3/16" which results in lack of reinforcement.

Face Weld -- Lack of Reinforcement, Test No. 440

FIGURE 6-17

6.3 TIME STUDY

The production time to weld 40 ft. erection seams with the one-sided single pass SAW Process is approximately 11 to 13 hours (w/o repair time). The production time to weld a 40 ft. erection seam with the conventional processes is typically 16 hours.

SINGLE-PASS ONE-SIDE SAW ERECTION WELD PROCESS

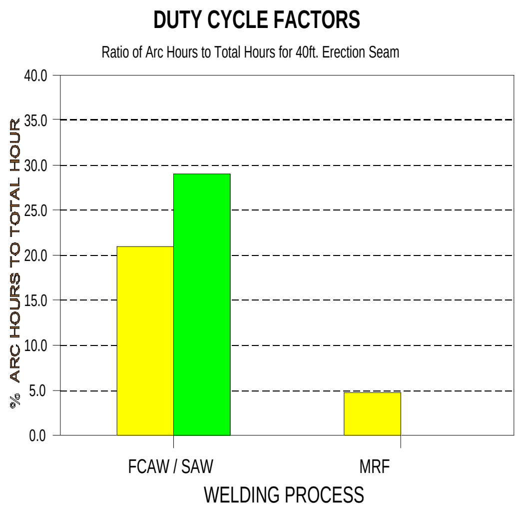
MATERIAL Gr. – AH-36

A2 Blocks:	242 / 244	246 / 248	241 / 243	245 / 247	313 / 395	315 / 399	314 / 396	314 / 400
Seam Type	Port	Port	Stbd	Stbd	Port	Port	Stbd	Stbd
Seam Length	40ft.	57ft.	40ft.	60ft.	46ft.	40ft.	43ft.	40ft.
JOINT PREPARATION AND WELDING TIMES (Unit of measure in hours)								
Tack welding (1) :	0.5	1.0	0.5	1.0	0.75	0.5	1.0	0.5
Remove Fitting Aids / Grind :	1.0	1.5	1.0	1.5	1.0	1.0	1.0	1.0
Backside Grinding (2) :	2.0	2.5	2.0	2.5	0.5*	0.5*	0.5*	0.5*
Tape Application :	2.5	3.5	2.5	3.5	3.5	3.0	3.5	3.0
Track & Equipment Setup :	2.5	2.5	2.5	3.0	2.5	2.5	2.5	2.5
Iron Powder Addition :	0.5	0.75	0.5	0.75	0.5	0.75	0.5	0.5
Arc Time :	0.5	0.75	0.5	0.75	0.5	0.5	0.5	0.5
Top side Slag Removal :	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Tape Removal / Cleaning :	1.5	1.5	1.0	1.5	1.0	0.75	1.0	1.0
Track and Equip. Storage :	1.0	1.5	1.0	1.5	1.0	1.0	1.0	1.0
	12.5	**16.0**	**12.0**	**16.50**	**11.75**	**11.0**	**12.0**	**11.0**
REPAIR TIME								
Root Pass / Cover Pass:	4 / 0	40 / 0	12 / 0	4 / 0	4 / 0	0 / 1.5	1 / 0	0 / 0
TOTAL TIME :	16.5	56.0	24.0	20.5	15.75	12.5	13.0	11.0

(1) Joint pre-fit with stud welding attachments, practice is common to both processes so time is not included.
(2) Backside grinding consists of grinding tack welds flush and rust removal.
* Rust removal only / tacks not ground flush

TABLE 6-4

Erection joints prepared for the single-pass one-side SAW process must be tack welded prior to removal of joint fitting aids to maintain plate fairness. Fairing aids are removed and studs ground flush with deck. Before applying backing system the root side is prepared by grinding tacks flush and removing all rust. In the last four erection joints (marked with asterisk on previous page) the root backing is applied before the joint is tack welded. Adequate penetration is achieved through tack welds with the modified parameter settings of (WPS) NP-7A2.6E. The chart below displays ratio of arc hours to total hours for each process. Arc times for the conventional process are approximately 4.0 hours per 40 ft. seam and 0.5 hours per seam with the MRF process.

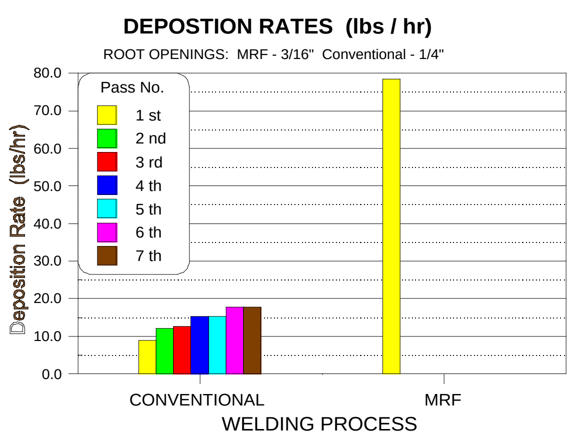


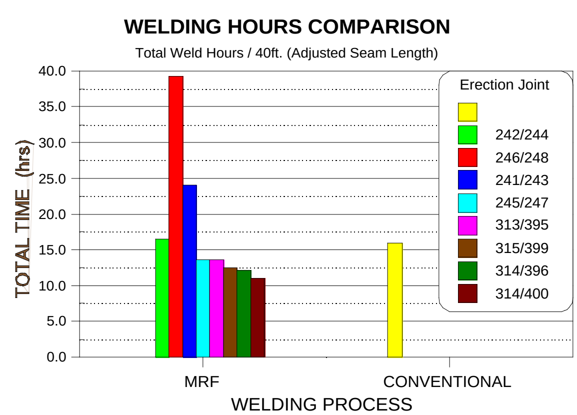
CONVENTIONAL PROCESSES

	--- FCAW ---		***--- SAW ---***
PASS No.	1 2		3 4 5 6 7
EQUIP. SETUP	--- 1	TRACK / EQUIP. SETUP	--- 2
JOINT PREP.	--- 1	JOINT PREPARATION	--- 2
TAPE APPLICATION	--- 2	WELDING (arc time – 2.35hrs.)	--- 3
WELDING (arc time – 1.7hrs.)	--- 4	EQUIP. STORAGE	--- 1 .
PRODUCTION TIMES	**8 Hours**		**8 Hours**

TABLE 6-5

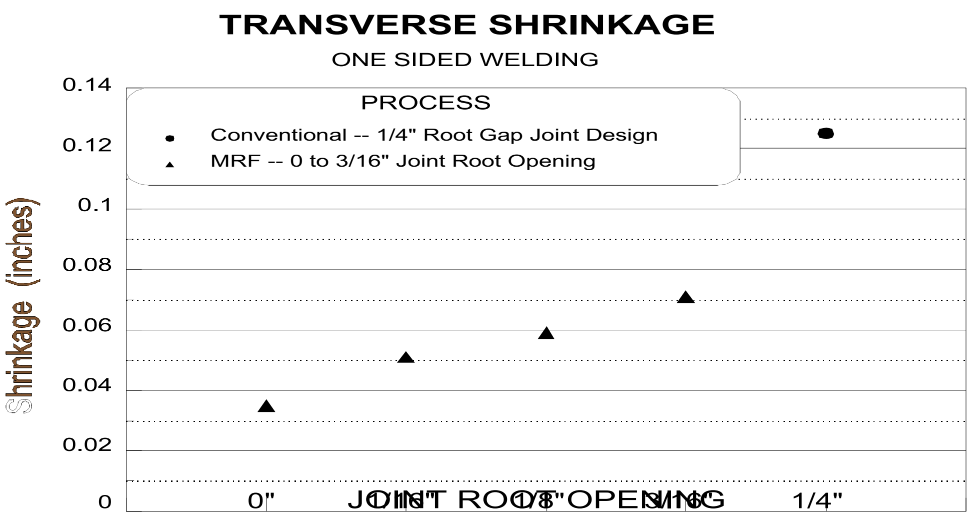
Weld deposition rates (chart below) of the individual passes are compared for both processes. The third chart shows total MRF welding hours per seam (time / 40ft. length) with repair hours included. The efficiency of the MRF process is demonstrated with the repair hours minimized in the last five seams.





6.4 TRANSVERSE WELD SHRINKAGE

Transverse shrinkage measurements are recorded at the weld start, mid-length, and weld end locations of each erection joint welded. Transverse shrinkage data is presented in the chart by joint root opening sizes, ranging from 0” to 3/16” and compared with the average transverse shrinkage of a joint welded with the conventional process (1/4” root opening) using the same joint bevel. The one-sided single pass MRF process minimizes the joints transverse shrinkage.



6.5 PRODUCTION WELDING SUMMARY

Parameter adjustments within the limits of PQR (NP-7A2.6) are required to account for the erection seams increased included angle of 45°. Tests welded with the adjusted parameters of (WPS) NP-7A2.6C with a range of root openings (0” to 1/4”) demonstrated acceptable visual characteristics. Ultrasonic and sidebend test results are also satisfactory.

(WPS) NP-7A2.6C				
LEAD ARC ***(AMPS /VOLTS)***	***TRAIL ARC*** ***(AMPS/VOLTS)***	***T.S.*** ***i.p.m.***	***ELECTRODE*** ***STICKOUT***	***IRON POWDER*** ***(FILL LEVEL)***
750A / 26 V	950A / 50V	18.0	1 11/16” / 3 _”	7/16”

TABLE 6-6

Six erection seams are welded with this (WPS) NP-7A2.6C and the joint conditions and inspection results for each seam are presented in the matrix, page 58. The face reinforcement satisfies visual inspection requirements but the root reinforcement results are mixed.

Torch head misalignment resulted in electrode offset from the joint's centerline causing lack of root reinforcement in the erection seam of Blocks 246/248. An additional tracking aid is attached to the carriage giving the operator another joint centerline reference guide.

The same root weld defects are identified in test plates prepared and welded with conditions simulating typical erection conditions (0" root opening, 40^{o} included V-Groove, 4^{o} joint declivity).

Further procedure adjustments are made in (WPS) NP-7A2.6E. The lead arc parameters have been modified and the iron powder fill level is adjusted to achieve acceptable root weld reinforcement. Test plates meet V.T. and U.T. inspection criteria and sidebend test results are satisfactory.

(WPS) NP-7A2.6E				
LEAD ARC (AMPS /VOLTS)	***TRAIL ARC (AMPS/VOLTS)***	***T.S. i.p.m.***	***ELECTRODE STICKOUT***	***IRON POWDER***
750A / 28 V	900A / 48V	18.0	1 11/16" / 3 _"	3/8"

TABLE 6-7

The next four erection seams are welded in accordance with (WPS) NP-7A2.6E and with these seams unlike previous seams the root backing material is applied before the joint is tack welded. These adjusted parameter settings give adequate reinforcement through tacks with no grinding requirements. An acceptable root bead contour is achieved with these adjusted parameter settings except for locations of weld rollover in two seams identified in locations with plate misalignment.

The average of total hours calculated from the last (4) erection seams welded with the MRF Process (hours / 40 ft. seam length) are between 12 to 13 hours. The labor hours are reduced approximately 25% from the times required with the conventional process. For the purposes of comparison an example is provided using a $20.00 labor rate.

LABOR COST COMPARISONS **(Labor Rate -- $20/hr)**			
		CONVENTIONAL SAW	*ONE-SIDED SINGLE PASS (MRF) SAW*
LABOR TIME (40ft. erection seam)	---	16 hours	12 hours
TOTAL LABOR COST	---	$ 320.00	$ 240.00

TABLE 6-8

CONSUMABLE COST COMPARISION

MRF PROCESS (3/16" Root Opening)

	Consumable Deposition (lbs/ft)	*x*	*Cost ($/Lb)*	*=*	*Cost / Foot of Weld*
5/32" Dia. EA1 Electrode	0.68		$ 1.62		$ 1.10
3/16" Dia. EA1 Electrode	0.77		$ 1.63		$ 1.26
Iron Powder	0.21		$ 0.31		$ 0.07
PFI-50 Flux	1.04		$ 3.71		$ 4.06

PROJECTED COST OF CONSUMABLES WITH RF-1 BACKING FLUX, $2.30/ft. -- $ 8.79

PROJECTED COST OF CONSUMABLES W/ CLOTH COVERED BACKING, $2.86/ft. -- $ 9.35

CONVENTIONAL PROCESSES (1/4" Root Opening)

	Consumable Deposition (lbs/ft)	*x*	*Cost ($/Lb)*	*=*	*Cost / Foot of Weld*
.045" Dia., E71T-1 Electrode	0.50		$ 1.33		$ 0.67
5/32" Dia., EA1 Electrode	0.93		$ 1.11		$ 1.03
761 SAW Flux (5 passes)	0.81		$ 0.99		$ 0.80
Temporary Backing	----		----		$ 1.50

PROJECTED COST OF CONSUMABLES -- $ 4.00

TABLE 6-9

TOTAL COST COMPARISION

CONVENTIONAL PROCESS			MRF PROCESS		
LABOR	*MATERIALS*	*TOTAL*	*LABOR*	*MATERIALS*	*TOTAL*
16 Hrs. @ $20 = $ 320	**$ 160**	**$ 480**	**12 Hrs. @ $20 = $ 240**	**$ 352**	**$ 592**
16 Hrs. @ $25 = $ 400	**$ 160**	**$ 560**	**12 Hrs. @ $25 = $ 300**	**$ 352**	**$ 652**
16 Hrs. @ $48 = $ 768	**$ 160**	**$ 928**	**12 Hrs. @ $48 = $ 576**	**$ 352**	**$ 928**

TABLE 6-10

The table shows that when the labor rate exceeds $48 / hour, the MRF process is more economical. When the labor rate is less than $48 / hour, the conventional process is more economical due to the high cost of the MRF welding consumables.

The apparent advantages this single pass one-sided welding process offer are:

- Reduced transverse seam shrinkage. Shrinkage values of process are less than half the typical conventional process seam shrinkage values.
- Satisfactory U.T. Inspection Results.
- The benefit of reduced labor hours (approx. 25%) seen in last (4) seams welded with modified parameters.

CONCLUSION

New one-sided single pass SAW welding procedures were developed utilizing a newly designed backing system.

- The procedure for 11/16" plate passed all testing requirements and was approved by ABS.
- This procedure was then demonstrated in production and 10 joints were successfully welded.
- The development work also produced acceptable welding techniques for 5/16" plate thickness.
- The backing system was used for over 177 test welds and 10 production welds without deterioration or damage.

Areas where future research and development could improve the weld process:

- The addition of a third electrode to weld greater thickness
- Modifications to the procedure to increase the travel speed to reduce the deterioration of the HAZ toughness. This would permit qualification of material with greater impact toughness such as EH-36.
- Investigate the potential of twin wire welding for a substitute of one of the welding electrodes
- Evaluate cored wires for either or both of the welding electrodes

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